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FIRST ANNUAL REPORT ON CACAO RESEARCH 1931

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PREFACE.

In introducing the first report on the working of this Cacao Research Scheme, it will probably prove of interest to place on record some account of the genesis of the Scheme, and in this note, therefore, the opportunity will be taken to recount certain facts in this connection.

By the year 1927, the Imperial College of Tropical Agriculture, which it may be remembered is a post war institution that only came into being in 1922, had settled down to the academic part of its duties. The Diploma course had been supplemented by a Post-Graduate course, and the curricula and lecture lists had been elaborated and tested out by two or three years' experience. Members of the staff had, therefore, more leisure for other matters, and serious attention was beginning to be devoted to a consideration of the research programme.

The development of the College on its present lines had been recommended in 1927 by the Committee set up by the Imperial Government to consider Agricultural Research in the Non-Self-Governing Dependencies. This Committee was first presided over by Lord Milner, but on his death the Chairmanship was taken over by Lord Lovat. The recommendations of this Committee were of the greatest importance and included such matters of policy as the formation of a unified Colonial Agricultural Service, the Colonial Agricultural Scholarship Scheme and the provision of post-graduate training with the object of maintaining a steady flow of trained recruits to that service. The Committee also envisaged the formation of a chain of Agricultural Research Stations to serve definite regions in the Tropics. The functions of these Research Stations were very carefully defined, and provision was made to avoid overlapping or clashing with the legitimate work of Colonial Agricultural Departments. It was recommended that the Research Stations should undertake long range research of a kind that could not ordinarily be undertaken by an Agricultural Department, whose officers are naturally expected by their respective Governments to deal with matters of local and more immediate economic importance. It was contemplated, therefore, that these Research Stations should supplement, but in no way replace, the Agricultural Departments, and it was clearly envisaged by the Lovat Committee that the Imperial College of Tropical Agriculture should function as one of these Central Research Stations. In the stress of the present times, caused by the prolonged and wholly unprecedented depression, the need for economy has delayed the execution of many of these schemes, and the recommendations of the Lovat Committee are perhaps rather apt to be forgotten. Nevertheless the general recommendations made were so fundamentally sound that it is impossible to conceive that they will not be revived again as soon as circumstances are favourable.

Some space has been devoted to the above Committee because the general rules laid down by it for long range research have been utilized by the College authorities as a guide, and have definitely led up to the conception of the existing programmes of the College Banana and Cacao Research Schemes.

Towards the end of 1927, it was decided to include cacao in the long range research programme of the College, and at my request, Mr. E. E. Cheesman, the Professor of Botany, prepared a memorandum entitled "Biological Researches on Cacao at the Imperial College of Tropical Agriculture". As the title implies, this memorandum envisaged botanical research only, but was based on the important fact that the crop is the chief one in the Colony in which the College happened to be situated, and is also a crop of major importance in other Colonies. Excellent work had been initiated by the Trinidad Department of Agriculture on their experiment station at River Estate, and the work done there had really emphasized the necessity for long range research, which was outside the means or capacity of the local Department. Professor Cheesman's scheme briefly indicated the necessity in the first place for higher yields, and secondly of improvement in quality, and these points have been fully dealt with in the reports that are now presented in this volume.

Mr. William Cadbury happened to be in Trinidad on a short visit in the early part of 1928, and the opportunity was taken to consult him. His advice and sympathetic enthusiasm were most encouraging. The College Advisory Committee and the Trinidad Agricultural Department were next consulted, and finally the scheme was placed before a special meeting of officials, merchants and cacao planters, which was called by the Principal at the College on Wednesday, 18th April, 1928. This meeting was very largely

attended and gave its approval, at the same time making suggestions for the wider application of research. In the scheme that was finally presented by the Principal to the Governing Body, provision was made for additional research work on cacao soils and on the economic side of cacao production. The decision of the Governing Body was that the economic enquiry should be financed from general College revenue, but that the work on cacao soils, envisaged by Professor Hardy, should be included in the Cacao Research Scheme in addition to the biological work embodied in Professor Cheesman's original report. The scheme, amended on this basis, was considered at the first meeting of the Colonial Advisory Council on Agriculture and Animal Health in London in January, 1929, and received its general approval, certain minor modifications and additions being left for final adjustment between Mr. F. A. Stockdale, the Agricultural Adviser to the Colonial Office and the Principal. The estimated expenditure as finally approved by the Colonial Advisory Council of Agriculture, was :—

Capital Expenditure ..	..£7,150
Recurrent expenditure	..£4,655

and included provision for a small estate, and for the recruitment of three research officers two botanists (a geneticist and a physiologist) and one soil chemist.

It was agreed that the scheme should be launched on a five-year basis, at the end of which period the whole position should be reviewed. It was also decided that contributions should be invited not only from the Governments of the cacao producing Colonies, but also from the manufacturers in Great Britain. The response to the appeal was on the whole fairly satisfactory, considering the fact that the first symptoms of the economic depression had already appeared. In April, 1930, the promises of financial assistance had amounted to the following :—

Capital Expenditure.

Government of Trinidad ..	..£1,200
do. Ceylon ..	.. 100
do. Grenada ..	.. 50
Messrs. Cadbury Bros. Ltd.	.. 1,000
do. J. S. Fry & Sons, Ltd.	.. 500
Total ..	..£2,850

Recurrent Expenditure.

Government of Gold Coast	..£1,000
do. Trinidad	.. 600
do. Nigeria ..	.. 500
do. Ceylon ..	.. 50
do. Grenada ..	.. 25
Messrs. Cadbury Bros. Ltd.	.. 500
do. Rowntree & Co.,	.. 250
do. J. S. Fry & Sons, Ltd.	200
Total	..£3,125

The sums contributed fall considerably below the estimates, and this is especially the case with regard to capital requirements. It was felt nevertheless that the funds actually promised warranted the launching of the scheme, especially as a small area available on the College estate would suffice for the preliminary investigations on root stocks, and because the purchase of an estate, although an essential part of the scheme, could possibly be postponed for a few months, when it was hoped that it would be possible to raise more funds.

Steps were accordingly taken to recruit the necessary staff, and accommodation was provided in the College Laboratories. Messrs. F. J. Pound and E. E. Pyke are the two botanists engaged, and they are working under the general supervision of the Professor of Botany. Mr. J. A. McDonald is the soil chemist, and his work is under the general direction of the Professor of Chemistry. These officers took up their duties in September and October, 1930, and the reports on their work which are presented in this volume are for the period from which they started work up to 31st December, 1931. A brief statement of accounts is appended to this report. It is proposed to present an annual report in future.

The generous willingness of Trinidad cacao planters individually to co-operate with the research officers and to provide facilities for investigations on their estates has contributed not a little to the progress that has been made, and this opportunity is taken to acknowledge it gratefully.

Finally, the closest contact between the research staff and all supporters of the Cacao Research Scheme is most earnestly desired, and constructive criticisms will be heartily welcomed.

Imperial College of Tropical Agriculture, Trinidad, 21st September, 1932.

G. EVANS, *Principal.*

* * *

A. BOTANICAL SECTION.

THE BOTANICAL PROGRAMME OF 1931.

BY E. E. CHEESMAN, M.SC.

THE botanical officers appointed for cacao research arrived in Trinidad on 1st November, 1930, and after arranging their laboratories, engaging assistants, and generally preparing, they were able to take up their programmes almost in full with the opening of the calendar year.

Aims.

As this is the first report, a brief recapitulation of aims, as laid down in the memorandum on which the cacao research scheme is based, may be not out of place by way of preface.

The problems of applied botany presented by crop plants can usually be divided for convenience of discussion into those of genetics and those of physiology, though in practice genetics and physiology are only two aspects of the same subject and prove inseparable. The problems of the cacao crop are no exception to the rule.

Broadly defined, the aim of the researches is the collection of information necessary for improvement of both yield and quality in the cacao crops of the Empire, with the economic object of increasing the profits of both the grower and the manufacturer. Improvement depends partly upon finding better trees to be grown, which is the genetic aspect, and partly upon discovering the best growing conditions economically possible, which is the physiological.

On the genetic side, we find the average cacao plantation to be a mixture of trees, good, bad, and indifferent, whether viewed from the standpoint of yield or from that of quality. This mixture needs to be sorted out, and the best elements in it, when found and propagated, should provide planting material not only far above the present average in both respects but also uniform, and uniformity in itself is highly desirable. The genetic problems are thus primarily problems of selection, but cognate to them are problems of propagation, for cacao will not "breed true" from seed, and isolation of good types without suitable means of propagating them would be largely lost effort. It is well known that cacao can be budded or grafted on seedling stocks, but by no means certain that existing methods are the most suitable for selected material, and there is scope both for study of the interactions of stock and scion in budding, and for investigation of new methods.

On the physiological side, the aim is ultimately to discover and describe in detail how the cacao tree lives and grows, and builds up its yield. Immediately, a much more restricted object is necessary if effort is to be concentrated efficiently, and it was decided at the outset that investigation of the factors influencing fruit-setting, with a view to reduction of the heavy losses which occur through shrivelling of young fruits on the tree, was the most urgent requirement in general physiology and should have first attention.

The detailed programmes were thus drawn up under three headings, which provide in general terms a convenient classification of the numerous subsidiary researches which are necessary, and these headings will so far as practicable be retained throughout. They are :—

(*a*) Propagation Studies.
(*b*) Genetic Survey.
(*c*) Studies of Fruitfulness.

Progress and Outlook.

Detailed accounts of progress along the various subsidiary lines are presented by the officers responsible for them, and the purpose of this introduction is to show how the papers presented fit into the general plan.

In propagation studies, at the outset, the whole range of general horticultural practice was open for investigation, and the first step was to narrow down the issue. Mr. Pyke's paper records his preliminary experiments to that end. The propagation problem really has two phases, first the question of how best to root material from selected trees, and secondly how best to multiply nursery stock once it has been initially rooted. It is, of course, always possible to bud on a seedling stock, but the technique of the process is well established, and as clonal stocks are essential for precise scientific work, even if not for the plantation, budding has been ignored for the time being, and effort concentrated upon inducing material to form its own roots. It appears from the preliminary results that softwood cuttings promise the best solution of the first phase, and layers or stools of the second. With the issue thus narrowed down it becomes possible to study further the optimum conditions for success with these two methods. In the course of 1932, propagation studies will be directed to the improvement of the technique, but at the same time a particular effort is to be made to raise a quantity of clonal material by the methods already established.

At the earliest opportunity when a sufficient number of vegetatively propagated plants can be obtained an experiment will be laid down to compare such plants against scions from the same mother trees on seedling stocks, and against seedling progeny of the same parents.

Mr. Pound's genetic survey for the year has been largely concerned with intensive measurements of a small number of trees in preparation for more extensive observations to follow. His first task was the determination of sampling units, and it is satisfactory to find that 30 pods are sufficient to characterise any tree with a high degree of accuracy with respect to pod dimensions which have an important bearing on final yield. Some of the incidental observations, such as those upon the effect on pod dimensions of position on the tree, are likely to acquire more significance later on, whilst discovery of unexpected variability in number of beans per pod, coupled with remarkable constancy in number of ovules per ovary, opens up a field of investigation which may well prove to be of first rate importance in yield problems.

In general physiology both officers made field observations of the periodicity of the tree and the relationship between vegetative growth, flowering, and fruit-setting. These observations, carried out weekly, represent a very considerable proportion of the year's work which does not figure in the body of the report at all. The data collected are extensive, and it has been judged better to withhold them than to risk the pitfalls which beset the interpretation of figures for a single season. Similar observations, with some modifications suggested by experience, are being continued, and after two or perhaps three seasons it is hoped that certain questions concerning tree behaviour will be answerable.

The evidence obtained of incompatibility and partial self-sterility in cacao clones sheds light from a new angle on the question of genetic variability in cacao yields, and is presented although it is clear that it is only the opening of a line of work which must be pushed deeper in 1932 and future years.

THE VEGETATIVE PROPAGATION OF CACAO.

I.—A Survey of Possibilities.

By E. E. Pyke, B.Sc.

When propagation work under the Cacao Research Scheme was started, the general problem was to find methods of obtaining clonal root stock material. At the outset, all the wide field of horticultural practice was open to investigation and it was necessary to find those methods which would be most likely to lead to practical success in rooting cacao. Further, two aspects of propagation had to be considered; firstly, the initial isolation of a desirable type, and secondly, the multiplication of the isolated type on a nursery scale. The methods appropriate to the first object will not necessarily be the best for the second, and it was considered possible that whilst the first problem might be solved by taking cuttings or budwood, the second would probably require some form of layering or stooling technique.

Methods.

Many of the various trials were carried out in the solar propagator, which has been described by Hunter.* The temperatures attained in this apparatus naturally show a daily fluctuation, and also vary from day to day with the weather, but in the dry season, when the sky is seldom overcast, the differences between days are probably unimportant. The daily cycle of changes may be advantageous or disadvantageous, and this point remains to be determined. At a later stage in the work an electric propagator was available, in which the temperature can be accurately controlled and kept constant, and comparison of the two types is proceeding.

Approximately constant temperatures were used for most of the experiments on callus, and were obtained by the use of electric light bulbs in suitably insulated containers.

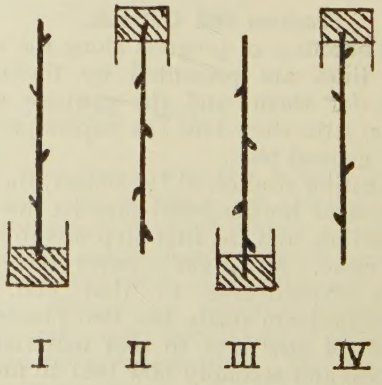
Hardwood Cuttings.

Some of the earliest experiments were made with hardwood cuttings. These were taken from fan branch material† of fairly vigorous growth, aged about two years. Stems of this age, if not of too rapid or too feeble growth, are about $\frac{1}{4}$ inch to $\frac{3}{8}$ inch diameter, and have a relatively small pith. They have shed their original leaves, and side shoots are not abundant. The cuttings were made to lengths of five inches, nine inches, or twelve inches, with slanting cuts just below the nodes at the bases and just above the nodes at the tops. The earliest experiments demonstrated that there was no difficulty in obtaining top growth when the cuttings were set with their bases in sand. In a few days the buds on the part of the cutting above the sand began to swell, and after about two weeks these had produced short shoots, two to three inches long, each with several small leaves. In most cases the buds about the middle of the part above the sand grew out—the topmost buds rarely made much growth. Although several fairly large batches were put in the solar propagator from time to time, no rooting was ever observed, and the top growth always died back after a few weeks. The bases of the cuttings did not callus appreciably if they were set in sand, and the cuttings slowly rotted from the base upwards.

For example, in one experiment in February, 1931, ninety-three cuttings from seven trees were set in the solar propagator, and after five weeks none showed any signs of rooting. In this case 38 had made some shoot growth, which at the termination of the experiment was beginning to wilt off; on the other 55 the buds had not grown out. The amount of shoot development from the buds varied widely from tree to tree, though whether for genetic or for physiological reasons it is impossible to say.

Most of the cuttings exhibited a proliferation of the lenticels below the sand level, and many had a very small callus ring at the upper end, in the air, but in no case was any callus formed at the basal end below the sand. One cutting had accidentally been put in upside down, and this had a fairly good callus ring at the morphologically basal end, in the air.

Callus Formation:—The next step was a study of the conditions for formation of callus. Forty hardwood cuttings were prepared from a single tree, each five inches long, and divided into four lots of ten, set up as follows:—



* Hunter, R. E.—Citrus Propagation. *Tropical Agriculture*, Vol. VIII, No. 4, 1931.

† For definition of terms used in this paper some note on the branch system of the cacao tree is necessary. The *main trunk* produced by the seedling divides at a certain height from the ground into three, four or five main branches, which together constitute what is known in Trinidad as the *jorquette* or *fan*.

These *fan branches* and their laterals of higher orders have their leaves arranged in two ranks, whilst the phyllotaxis of the main trunk is a $\frac{3}{8}$ spiral.

Other branches, sometimes called *water-shoots*, which grow vertically from the trunk or sometimes from the fan branches, have also a spiral phyllotaxis and are distinguished as *chupons*.

Series I.—Upright, bases in sand.
do. II.—Inverted, bases in sand.
do. III.—Inverted, tops in sand.
do. IV.—Upright, tops in sand.

These were kept under bell jars in a practically saturated atmosphere, held between 30°C. and 32°C. by means of an electric lamp. At the end of 13 days the amount of callus formed was estimated by eye, marks being given from 1 (small isolated patches) to 6 (end of cutting completely covered). The results were :—

Series.	*Top.*	*Base.*
I	17	0
II	7	6
III	0	50
IV	0	29

The most striking feature is the almost complete absence of callus in sand, only four cuttings forming any callus at all, with a total mark of 6 against 103 for the total callus in air. As a secondary result, the basal ends of the cuttings used show much better callus formation than the top or distal ends, the total mark being 85 against 24. Thirdly, the basal ends callus better when the cuttings are physically inverted. In short, aeration, polarity and gravity would each appear to play a part.

In an experiment on humidity, four lots of cuttings from one tree were suspended in air, inverted, over water and three solutions of sulphuric acid giving saturation deficiencies of 5 mm., 10 mm., and 15 mm., respectively. After ten days at a temperature of 30°C., the cuttings over water had made good callus, whilst those in the driest atmosphere had made practically none. Those in the other two unsaturated atmospheres were intermediate, the 5 mm. deficiency permitting rather more callus than the 10 mm.

It thus became possible to define conditions for callus formation on hardwood cuttings which, though possibly not optimum, could be adopted as standard with reasonable success, namely, saturated atmosphere, temperature 30°C. to 32°C., cuttings in air, inverted. In later experiments under these conditions, some batches had the ends almost completely healed over in ten days.

These standard working conditions having been determined, an experiment was made with batches taken at the same time from several different trees. It was found that there was considerable variation in the rate of callusing of cuttings from the different trees, and also marked differences in the extent of the bud development, indicating that internal factors were probably of importance. The general favourable results with callusing were obtained during the dry season, when the trees were not setting or maturing any crop and when there was little flowering. Later experiments under the same working conditions, but made during the wet season when the trees were fruiting, gave very poor results, practically no callus being formed.

Callused twigs, after ten days in moist air, were set in the propagator with their bases in sand. No rooting was observed on such cuttings, and bud development was poor in most cases; only a few cuttings made leafy shoots. At the time no experiments were made with the paring off of the callus, and it is possible that the absence of success was partly due to the resistance to water uptake imposed by the large and corky callus pads. On the other hand, later experience with softwood cuttings of cacao suggests that root formation is largely a question of carbohydrate nutrition, since the rapidity and extent of root initiation and subsequent growth seem to be roughly proportional to the number of healthy green leaves retained by the cutting. It may therefore be that the reserve carbohydrates in the hardwood twigs are insufficient for the nutrition of both callus and buds.

At this point the investigation of hardwood cuttings was left for the time being. The results suggested that it should be possible to obtain roots from them by suitable modifications of technique, but by the time that this conclusion was reached, concurrent experiments with softwood cuttings had indicated an easier approach to the propagation problem, and with economic requirements in mind, attention was subsequently devoted almost wholly to the softwood material.

Root Cuttings.

In the early stages of the survey a number of root-cuttings were taken from a single tree and potted up in a mixture of sand and coconut fibre in the green-house. They were cut about six inches long, and graded according to diameter into three classes, viz.: under $\frac{1}{4}$ inch, $\frac{1}{4}$ to $\frac{1}{2}$ inch, and $\frac{1}{2}$ to 1 inch. The number set was 88, and some remained alive for several months, but there was no sign of root or shoot formation on any of them, and the preliminary observation did not seem to warrant any further work along this line for the present.

Softwood Cuttings.

The degree of success obtained with softwood cuttings has varied greatly from batch to batch, although the external conditions were comparable in most of the trials, and as far as possible similar material was used. The best rooting percentage was obtained with a batch of 20 cuttings taken from vigorous, two-year-old trees in October, 1931. Of this batch only one decayed at the end, and 18 rooted to a greater or less extent, being equivalent to a rooting percentage of 90. This order of rooting has been obtained in several other trials of small numbers of cuttings, and there is no doubt, in view of these results, that improved adjustment of internal and external conditions will result in a consistently high proportion of well rooted cuttings.

Type of Material used.—Fan branch "flushes" were used. Most of the best rooting material has been taken from young trees, which were capable of vigorous but rapidly maturing flush growth. Vigorous flushes which have just reached maturity seem to be the best for propagating, and although

short flushes have been rooted, long flushes (from six to nine inches in length) have rooted more readily and made better new shoot growth after rooting. The greatest problem in rooting cacao cuttings is that of leaf-dropping. This occurs to some extent in softwood cuttings of most plants, but it is particularly marked in cacao, and seems to be the chief limiting factor in determining success in rooting. This factor will be discussed later, but certain kinds of cuttings seem to be more liable to leaf-drop than others, more especially those with pale green or yellowish-green leaves, or with particularly large leaves. Many cacao trees under ordinary cultivation rarely make the right type of young growth for softwood cuttings, the flushes being short and with thin stems. Such trees might produce flushes of the necessary vigour if fairly heavily pruned.

Setting of Material.—The flushes selected were uniform as far as the available supply permitted, with clean stems and undamaged leaves. The stems were young enough to be quite green on the underside. They were cut several inches longer than the desired final length and transported in air-tight vascula or in moist sacking, guarded from sun and heat. At setting, a clean slanting cut was made with a heavy razor at an internode, so as to form a cutting about 6 inches to 9 inches long. Experiments were tried, with cuttings dipped in water and in "tanglefoot" before setting. Dipping in water was not satisfactory, as the cuttings tended to rot at the ends. It seems best to set the cuttings in sand without any previous treatment, although dipping in "tanglefoot" does no harm and may be useful in cases where the ends tend to rot.

The Medium.—A fairly coarse-grained, calcareous sand has been used for rooting. Even with this sand some packing, with consequent waterlogging, tends to occur. A sand of uniform round grain of about 1.0 mm. diameter would perhaps prove better. All the experiments with cacao show that optimum aeration is necessary for good wound callus formation, so that the rooting medium must allow uninterrupted access of air. In a well-draining sand of fairly coarse grain, irrigation with fresh air is ensured by the draining through of the water when the sand is watered, but if the sand packs, so that the intergrain spaces are very small, these become largely water-logged and aeration at time of watering becomes impossible. The influence of the grain size of the sand used is at present under detailed study, as it appears to be a most important factor.

Temperature.—Temperature, light and humidity are closely bound up with each other in the manipulation of the propagator. Thus, on the one hand frequent waterings, necessary during the heat of the day to maintain humidity above the coarse sand used, tend to reduce the temperature of the rooting medium, in spite of the bottom heat, to that of the water used. On the other hand, exposure of the propagating chamber to adequate light has in practice involved exposure to sunlight, and although the glass lid is covered with a layer of white cloth and frequently sprayed with water, the temperature of the air inside has undoubtedly been raised by radiation from above.

In consequence of these two effects, it is doubtful whether during the middle daytime there is ever inside the solar propagator a temperature gradient from sand to air in the direction generally believed to be advantageous. Measurements made on a sunny day, at all events, show the air in the propagating chamber to be two to three degrees centigrade above the outside shade temperature, with the sand at or slightly below the outside value, *i.e.*, usually in the region of 30-32°C. Towards evening, however, with the sun declining, watering is stopped at 4 p.m. and the temperature of the sand at first rises, and then falls much more slowly than that of the outside air, whilst the temperature of the air above the bed, though lagging behind that of the air outside the propagator, falls much more rapidly than the temperature of the sand. Thus a gradient is established in the right direction about sundown and persists all night.

That these existing temperature relations in the solar propagator are not altogether unsatisfactory is proved by the results obtained, but there appears scope for improvement in the daytime conditions, and attempts are now being made to keep the sand warmer by warming the irrigation water, and the air cooler by altering the shading so that no direct sunlight falls on the propagating chamber.

The ideal temperature should evidently be high enough to stimulate good callus growth, and low enough to avoid unduly intense respiration, injury to leaves, or check to photosynthesis. Unfortunately we have no experimental data on the optima for the physiological processes in cacao. On general principles, an excessively high temperature during the day must decrease the apparent assimilation rate, probably due both to a diminution of actual assimilation and to an increase of respiration. We should not expect optimum photosynthesis during the day to occur at temperatures above 30°C., and it does, therefore, seem that effort should be directed towards cooling the air above the cuttings as far as may be practicable.

Light.—Different amounts of shade have been tried for the softwood cuttings during propagation. Very heavy shade, as would be expected, is not suitable, as very little callus is formed and no roots develop. On the other hand, with very light shade or with no shading at all, it is impossible to keep the temperature low enough to prevent scorch, and the humidity also becomes too low. With the solar propagator, a single layer of white cloth is used over the glass frame. A "tent" of a single or double layer of the same cloth has also been tried inside. A double layer was found to give too heavy a shading, and even a single

layer is probably too much, unless of very open material. At present a single layer of cheesecloth is being used. It appears that the light relations are subsidiary to the temperature. The maximum lighting consistent with keeping down the temperature of the air is likely to prove the optimum.

Humidity.—With cacao cuttings, which have relatively an enormous leaf surface, an atmosphere of practically no saturation deficit must be maintained during at least the first three weeks, whilst the cuttings are callusing and rooting. After the roots have formed, slightly less humid conditions can be tolerated. In practice, a layer of moist cheesecloth spread over the cuttings and supported on porous pots filled with water, was found to give the best results. This cloth was removed after the cuttings had rooted (three to four weeks), as the first step in the hardening off process.

Nutrition.—Since the principle of softwood propagation is to use actively photosynthesising material, an important condition for successful rooting is to keep as many healthy leaves as possible on the cutting. Then, provided photosynthesis is not limited unduly by weak illumination, the probability of rooting will be high. However, humidity and temperature conditions have to be nicely adjusted, to prevent the leaves from becoming yellow, and from dropping. If a saturation deficiency of more than a very slight amount is present for long, especially if the air temperature is above 30°C., the leaves gradually turn yellow and fall. If the air is very dry and hot, as may occur if direct sun is allowed to fall on the glass top of the frame, the leaves turn brown rapidly, without being shed, and the cutting dies. It is possible that both water deficit and high respiration play a part in leaf yellowing and abscission, although certain cuttings will often show yellowing when under cool, humid conditions, when others keep quite green and healthy practically indefinitely. The leaf yellowing and shedding is not necessarily due to rotting at the ends of the cuttings, as usually they show no signs of decay and have formed callus, and sometimes root initials. *In no case has production of roots ever been observed on a cutting which has shed all the leaves, although such cuttings may have root initials already differentiated in the tissues at the base.* In such cuttings the apical bud usually attempts to push out new leaves, but these soon wither and the cutting dies.

When the importance of the green leaf to the cutting was realised attempts were made to hasten rooting by increasing artificially the supply of carbohydrates in cuttings. This was done by ringing flushes 10 to 15 days before removing them as cuttings, so that the phloem connection with the stem below should be broken and the flushes become gorged with accumulated products of photosynthesis. Such flushes, examined ten days after ringing, showed very heavy starch accumulation, particularly in the pith and the rays whilst the ring had stimulated considerable growth of wound callus. After severing, however, the leaves were soon shed and practically no additional callus was formed. A few kept some leaves and made fairly good callus growth, but no roots or even root initials were detected. The axillary buds on the ringed cuttings pushed, and short leafy shoots were formed on several cuttings, but these eventually died back. Control cuttings, taken from similar but un-ringed flushes, did not give a very high rate of rooting, as considerable leaf-drop occurred, but there was less leaf-drop, less bud growth, and more root development than on the ringed cuttings. No attempts at direct injection of cuttings with sugar solutions have been made, owing to the difficulty of making cuttings absorb at the cut ends, due to blocking of the wood by mucilage.

Aeration.—Access of oxygen to the base of the cuttings is necessary for the initiation and development of a wound callus in cacao. The respiration of these callus tissues under healthy conditions is possibly very active, and free gaseous interchange is therefore important. In a badly oxygenated medium, regeneration is inhibited and rotting can occur. However, with good aeration, callusing at the cut ends of cacao softwood cuttings is certain and rapid, and in very few cases has failure to root been due to failure to callus. No experiments have been made on the effect of aeration upon rooting, as opposed to callusing, but general experience suggests that rooting would be poor under conditions of bad aeration.

Subsequent Treatment.—If conditions have been right, cuttings should have short roots emerging just above the pad of callus at the end, in about three weeks after striking. The roots grow fairly rapidly, and after four to five weeks a vigorous cutting should have several roots 2 to 3 inches long. At this time also, new top growth should be showing. Either the terminal bud or the laterals may push out shoots, but in most of the cuttings so far established, the terminal bud has taken the leading part, producing a new "flush" of young growth similar to that of a fan branch on the tree. The most successful batch of cuttings raised, as regards continued top growth after rooting, was not "lifted" until the first flush of new top growth had matured, *e.g.*, eight weeks after striking; the cuttings were then carefully transplanted, without disturbing the roots, into pots prepared with compost. The potted-up cuttings were left for about a further three weeks in the solar propagator, and then transferred to a cool frame, and later to the greenhouse (Plate I, Fig. 1). In the cutting photographed, 13 weeks after setting, the first new flush has matured and a second new flush is growing rapidly; at the same time lateral shoots also are pushing.

It is important to handle the rooted cuttings carefully when transplanting, as the roots are easily broken off at the point of emergence. To avoid the necessity for transplanting at all, trials are being made with cuttings in waxed paper

pots, filled with the rooting medium, which are sunk level in the propagator. When lifting the cuttings, the complete pot will be taken out and transferred to a larger flower-pot of compost, after slitting it to ensure quicker disintegration.

At the time when 90 per cent. rooting was obtained, only six of the eighteen rooted cuttings were sufficiently vigorous, after six weeks in the propagator, to withstand potting up and hardening off, although probably more would have been successfully established if they could have been spared a longer time in the propagator. As presumably the ability to stand transplanting is related to the vigour of the root system produced, the best rooting conditions would improve the percentage of established cuttings.

Stools and Layers.

Aerial layering, or marcotting, in which ring-barked branches are surrounded by a moist rooting medium such as moss, has been found possible with cacao in Java (1) and in Ceylon. Furthermore, both stooling and layering occur naturally and not infrequently. The rooting of basal chupons (or vertical water shoots) is a common phenomenon on old cacao plantations, but apart from this, even chupons well above ground level can sometimes be seen to have formed roots from their bases under damp conditions, without being earthed up. When a cacao trunk falls so as to lie prone, it sends up a thicket of such young vertical shoots, each of which may put down a strong main root into the soil. Myers (2) describes this method of propagation as being very common with wild cacao in its natural habitat in Surinam. Whilst young shoots rooting under these conditions must be exceptionally well placed with regard to water and nutrients, with the main trunk of the tree to call upon, their behaviour serves at least as an indication that it should not be inherently impossible to multiply cacao by similar means under nursery conditions.

Stooling.—At the time when these investigations commenced, there was available for examination an experiment laid down in the previous year by Lowe (3). Twelve one-year old seedling trees of average Forastero type had been cut back to a few inches from the ground, and shoots allowed to grow from the stumps. Every other stump had been covered with an inverted plant pot so that its shoots should develop in darkness. There were thus six etiolated and six "normal" stools. When the shoots were several inches long, they had been mounded up with a coarse river sand. Examination of these stools about six months after the mounding, showed a scanty root development on nearly every stem, the roots being fibrous and ramifying in the surface soil. No significant difference in root production could be detected between the etiolated and the non-etiolated stems, and in neither case was the root-system adequate to support the stems independently of the mother stool.

A similar experiment was made with a number of seedlings about one year old from the wild Surinam cacao described by Myers (*loc. cit.*). The seedlings were cut back on 22nd December, 1930, and mounded up with fine sand on 6th February, 1931, when they had each produced four or five sturdy chupons. Nine months later they were examined, and it was found that roots had grown out of the earthed-up portions of nearly all the shoots, but, as in the earlier case, the development was poor and inadequate to support the chupons independently. Again the roots were fibrous and tended to run mainly horizontally.

Some form of manipulation appeared necessary to induce rooting of the required type, and a ring of bark was therefore removed at the base of some of the shoots. After time had been allowed for partial healing of the cuts, the stools were again earthed up. Three months later (on 11th February, 1932) the shoots had formed many new roots above the rings and new root production was still progressing. The new roots above the rings were sturdy and tended to grow vertically. No new root production was noticed below the rings.

In a third experiment, a batch of trees about 18 months old were stooled in February, 1931, and the resulting stool shoots were earthed up at the bases in August. When examined in November, there was very little root growth. It is probable that manipulation will be necessary. The shoots are being ring-barked or constricted with wire at the bases and are to be earthed up for another period.

One tree has given a striking demonstration of the production of roots above a ring. This was a young tree which had been pruned so as to form several chupons. Several of them were sickly, but one, of more vigorous growth, was selected and ringed near the base. A large callus formed at the top end of the cut, but did not join up with the stem below the ring. The stem above the ring thickened considerably, and a bud just below the ring grew into another chupon. After four months the stem was earthed up above the ring, and after a further four months the earth was washed out. Both the stem above the ring and the young chupon which grew from below it had made roots (Plate I, Figs. 3 and 4). The stem above the ring, however, had made a strong, vertically descending main root with many laterals, a really good root system, similar to that of a seedling, but the young chupon made very much less root growth, although a main vertical root was formed. In young cacao stools it seems that unless the stool shoots are partly isolated in some way from the main root system of the stool, nearly all the food manufactured in the shoots is translocated to it, and development of roots upon the stool shoots themselves is retarded.

(1) van Hall, C. J. J. *Cocoa*, pp. 144-146.
(2) Myers, J. G.—Notes on Wild Cacao in Surinam and in British Guiana. *Kew Bull.* (1930), 1–10.
(3) Lowe, B. A.—Unpublished Dissertation in the I.C.T.A. Library.

PLATE I.

FIG. 1.— *An established softwood cutting.*

FIG. 2.—*Chupons rooting from a layer.*

FIG. 3.— *A rooted stool.*

FIG. 4.—*Stool of Fig. 3 dissected. On the right, the stem rooted above the ring; on the left, the rooted shoot from below the ring.*

Layering.—A row of the Surinam trees were layered in December, 1930, when the others were stooled. The leaves were cut off and the seedling stems were pinned along the ground, without covering. Buds along the uncovered stems sent up shoots, but only very few were produced and these did not make good growth. The top growth was very much less than that made in the same time by the corresponding stooled stems. The bases were earthed up on 6th February, 1931, and were examined again on 4th November, 1931 (nine months). Rooting was poor; only a few fibrous roots were formed and no main roots were sent down by the vertical stems. They were then earthed up again, to see if rooting would be improved after a further period.

Young Forastero seedlings, about 18 months old, were layered (December, 1930) by pinning the main axis along the surface of the soil, after cutting back the fan branches to within a few inches of the jorquette. These small lengths of the fans were left, to see whether the shoots developed from them would also be fan shoots. Covering with soil was found to prevent the pushing of the buds on the layers, and one layer which was kept just covered died after a few months without making any shoots. The others developed shoots which were chupons upon the main chupon axis and fans upon the fan branches. After seven weeks the bases of the young shoots were mounded up with earth, to encourage rooting. The bases were washed out after about nine months, and the shoots were found to have made good roots (Plate I, Fig. 2). Both chupon and fan shoots sent down strong main roots with laterals, similar to seedling root-systems. The chupon shoots had already made the jorquette at this time, at a height about nine inches to one foot above the layered stem. In respect both of the top growth and of root development, the young layered Forastero trees were very much better than the Surinam wild cacao. This is rather surprising, since, according to Myers (*loc. cit.*), regeneration by a form of natural layering is general in the wild habitat of these trees. However, the Surinam trees were quite young when they were layered, and it may be necessary for them to make a stronger main axis before being pinned down.

Outlook.

It has been shown that cacao can be propagated by softwood cuttings and by stooling or layering, and it remains for further work to place the technique on an economic basis. In this connection there remains much to be done. In the first place there is an important gap in the evidence to be filled, as it is not yet possible to say that stems raised from cuttings will stool or layer as readily as the young seedling trees which have perforce been used in these initial stages.

For the raising of clonal rootstocks alone, the stooling of seedlings may have a use, and in this connection the influences of age of the material and season of the year upon rooting are to be investigated. It is the general experience in temperate horticultural practice, that the time factor is of great importance in determining success of rooting, and that apparently unpromising material may root if left undisturbed for a longer time than normal. In an experiment planned, seedling plants are to be stooled and layered at different ages, and comparisons are to be made of the number of young shoots produced per plant, their rate of top growth and of root development. Plants are also to be stooled and layered throughout the year, and the extent of shoot and root growth during different months is to be compared. In the experiments already conducted, the young plants were stooled and layered at the end of the wet season (December), so that the new shoots were developed during the dry season. The mounding up was done during the dry season and the shoots continued mounded up during the following wet season (May-December), during which they made considerable top growth and also developed roots. Thus new rooted stems were obtained within a year.

The best rooting medium was found to be a compost, composed of soil and vegetable debris. Rooting will occur in fine or coarse sand, but sand dries out rapidly and must be mulched with cut grass and watered regularly in the dry weather. Soils, even the compost soil used, tend to pack, and thus make it difficult to lift the rooted plants without injury. There is thus scope for much work in the determination of the best rooting medium.

Clonal material from softwood cuttings must obviously be tested as soon as sufficient is available, to see whether it is amenable to stooling or layering. Meanwhile, another type of clonal material is being investigated in which a seedling rootstock is used as a "nurse" for a bud-scion. Budded plants have been layered by mounding up the bases after ring-barking or constricting. In this way it is hoped to obtain the scions independently rooted. If the method is successful, it promises several advantages. Seedlings could be planted and budded, and the rooted scions established *in situ* without any disturbance to the roots beyond that involved in unearthing the seedling stump and severing the connection with the scion. It should also be useful in that chupon material could be easily isolated by taking budwood from chupons, whereas such material is not always available in suitable form for propagation by the softwood cutting method.

Summary.

Hardwood and softwood cuttings, root cuttings, stools and layers were tried in a preliminary survey of the possibilities of propagating cacao vegetatively on its own roots.

Hardwood cuttings were not rooted, but the conditions under which callus forms were determined.

Softwood cuttings, stools and layers were sufficiently successful to justify further study.

THE GENETIC CONSTITUTION OF THE CACAO CROP.

By F. J. Pound, B.Sc.

Introduction.

Aims.

The investigations reported in this paper are part of an attempt to lay a sure foundation for the subsequent selection of desirable types of cacao trees to be propagated as clones.

The material available for selection is, broadly speaking, the cacao tree population of the island of Trinidad, and it is doubtful if a better population for the purpose exists anywhere in the world. Prior to 1727, Trinidad grew Criollo cacao, but in that year the cultivation perished in some catastrophe rather ambiguously recorded as a "blast".

About thirty years later the Forastero cacao was introduced, which has been grown ever since. Trinidad Forastero is that extraordinary mixture of types called Trinitario, and contains almost every combination of characters possible to cacao, from Angoletas, scarcely distinguishable from Criollo, to typical Calabacillo at the other end of the scale. It is highly probable also that the inherent variability of the introduced Trinitario was enhanced by crossing with remnants of the old Criollo plantations, and it can scarcely be doubted that among the present-day crop, trees must exist almost ideal in their combination of yield, hardiness and quality of product.

The main problem is to find such trees, and as the total number of trees in Trinidad cannot be less than fifty million, anything like a complete survey of them is obviously a physical impossibility. The utmost that can be expected is a survey during the next few years of about 0.1 per cent. and it is required so to arrange the sampling that the records shall be truly representative of the whole population, and especially that outstanding combinations of desirable characters shall not be overlooked.

The preliminary work of this year has therefore been directed towards an estimation of the statistical variability exhibited by the crop as a whole. The estimation has inevitably been based upon a small sample, but from the limits found in that sample it will be possible to formulate provisional criteria for judging the merits of individual trees noted in the course of survey as promising.

Material and Methods.

The experimental material consists of three blocks of 100 trees each, situated on estates in three different valleys of the Northern range. These trees were numbered individually at the beginning of the year, and a complete record has been kept of their crop, the characters of every pod being observed at the time of picking. Two of the blocks are of ordinary crop trees, growing under conditions representative of good commercial estate management. The third is part of a spacing experiment on River Estate, the cacao estate of the Trinidad Department of Agriculture, but except for the fact that the trees are younger, conditions are very much the same as on the other blocks. Estate cultivation has followed its usual routine in each case throughout the year, without any modification being introduced by the experiment. Notice was given by the estates when the fields containing the blocks were to be picked, and arrangements were made to be present for examination of the crop. The crop lasted from January to July, and pickings between July and December were so small that they have been omitted. There was one picking in December, 1930, which was missed, but with this slight qualification the figures represent one complete season's crop.

Characters Recorded.

The characters chosen for observation were subject to the condition that they must be precisely measureable, and the complete list drawn up ran as follows :—

Number of pods.
Weight of pods.
Length of pod.
Diameter of pod.
Thickness of pod shell.
Weight of beans per pod.
Number of beans per pod.

Qualitative notes on pod type and cotyledon colour were added for general reference.

The weights could not be taken at the beginning of the year, until a suitable machine for field use was obtained ; subsequently the weight of the pod was found to be unreliable owing to variation introduced by degree of ripeness, and data concerning weight of beans will be published later when a full season's records are completed. The number of pods produced by a tree in a year is so vitally connected with the question of total yield that it will be discussed later in separate papers.

Statistics of Pod Dimensions.

Errors of Measurement.

The first steps taken were to ensure the accuracy of the technique of measurement of the linear dimensions, which were read off to the nearest millimeter from sliding callipers. *Length of pod* is definite, and the maximum error being 0.5 mm., or about 0.3 per cent. of the average reading, is negligible. In the case of *diameter*, it has to be remembered that there are an

indefinite number of diameters, not necessarily equal. By measuring always across a ridge on the pod, the possible readings are reduced to ten, and when ten measurements were made on each of ten pods taken at random from a heap from different trees, the results were :—

Table of Diameters. (In mm.)

1	2	3	4	5	6	7	8	9	10	Mean.
88	87	86	85	87	89	85	87	85	87	87
101	99	97	103	98	99	100	101	99	99	100
90	87	91	89	88	92	88	87	86	89	89
87	85	84	85	84	85	84	84	86	84	85
69	68	68	70	70	68	68	69	69	67	69
77	77	80	80	77	77	78	79	77	78	78
85	86	88	85	88	85	87	88	88	87	87
83	85	85	81	82	86	83	84	83	82	83
79	77	78	80	81	78	80	80	79	80	79
80	80	83	81	81	82	80	81	81	80	81

Analysis of Variance of Pod Diameters. (In cm.)

Due to	D.F.	Sum of Squares.	Mean Square.
Between pods ..	9	71.70	7.98
Within pods ..	9	0.005	0.0006
Interactions ..	81	1.67	0.0206
Total ..	99	73.375	

The measurements from different pods are significantly different, but the ten from one and the same pod are significantly *not* different. This shows quite definitely that a single measurement of each pod gives a sufficiently accurate estimate of the diameter.

Thickness of pod shell is the smallest in magnitude of the linear dimensions, and an error of 0.5 mm. may be equivalent to as much as ten per cent., but the errors will cancel out on a number of readings. There are again ten possible measurements, one through each of the ridges on the outside of the shell, and the possible errors thus introduced were likewise put to the test of experiment. Measurements on each of ten pods gave :—

Table of Shell Thicknesses. (In mm.)

1	2	3	4	5	6	7	8	9	10	Mean.
15	15	15	15	15	15	16	14	16	16	15
13	11	11	10	10	10	10	11	11	12	11
17	18	17	17	17	18	17	17	16	18	17
16	18	17	14	15	14	15	15	16	16	16
22	23	22	20	23	21	24	25	23	23	23
14	13	16	16	12	13	13	13	13	13	14
17	20	19	17	17	16	17	15	16	18	18
9	9	9	8	9	9	8	9	9	9	9
14	16	19	15	15	17	15	15	17	16	16
15	16	14	15	14	15	15	15	14	16	15

Analysis of Variance of Shell Thicknesses.

Due to	D.F.	Sum of Squares.	Mean Square.	$\frac{1}{2}$ Log$_e$.
Between pods ..	9	12.60	1.400	0.1683
Within pods ..	9	0.179	0.0199	$\bar{2}$.0415
Interactions ..	81	0.92	0.0114	$\bar{3}$.7630
Total ..	99	13.70		

Again, whilst the measurements from different pods indicate very significantly different populations, those from the same pod are not significantly different, and a single measurement per pod should afford a sufficiently accurate estimate of shell thickness.

Calculated Constants.

The extremes of pod *shape* are the Criollo type, long and narrow, and the Calabacillo type, almost spherical. The ratio of length to diameter would therefore appear to be a useful index of

shape. The means and standard deviations of the ratio for samples from each of ten trees were found to be :—

Table of Ratios.

No. Pods.	Mean of R.	S.D.	R. of Means.	Difference.
28	1.79	0.1000	1.78	—.01
39	1.89	0.0934	1.89	—
44	1.81	0.1148	1.82	+.01
25	1.80	0.1371	1.79	—.01
29	1.86	0.1780	1.85	—.01
24	2.13	0.1859	2.12	—.01
44	1.94	0.1430	1.94	—
30	2.02	0.1591	2.02	—
23	2.08	0.1876	2.07	—.01
77	2.26	0.1289	2.25	—.01

The variance within the crop of a single tree at one picking is small, and the ratio of mean length to mean diameter may therefore be used instead of the mean of ratios calculated for each pod separately, which saves calculations. The "ratio of means" is added in the table for comparison with the mean ratio, and the discrepancies are clearly negligible.

The relation between the linear dimensions, which are easily obtained, and the *volume* of the pod, which is not easily measurable in the field, was the subject of a test in which a number of pods of all shapes and sizes were measured in the laboratory by displacement of water. The ratio of the true volume so found, to the quantity LD^2 (where L is the length and D the diameter of the pod) varied from 0.37 for the longest and narrowest pod to 0.51 for the roundest, with a mean at 0.45. The formula $V=0.45\times LD^2$ may therefore be used to give a close approximation to the volume of a cacao pod, especially if it be of the intermediate or Amelonado type, and corrected formulae can be employed if necessary for extreme types.

After the above formula had been evolved, it was discovered that Waters, Hunter, Poynter and Monu* had previously reached an identical conclusion in a slightly different way. They suggest the formula $V=\frac{L(\pi D)^2}{22}$, based on that for a prolate spheroid, with the constant determined experimentally. Putting $\pi=\frac{22}{7}$, their formula reduces to $V=0.449LD^2$, a remarkable agreement proving that the same rule is applicable to both Trinitario and West African cacaos.

Analysis of Data.

The completed data are complicated by the fact that they comprise records distributed over three localities in space and over seven months in time. This distribution was intentional, in order that the maximum amount of information might be extracted, and it necessitates analysis for both factors. The analysis for locality is conveniently accomplished by presenting separate frequency curves for the whole crop of each of the three blocks, and the analysis for time of year by comparing the January pickings with the later pickings and with the year's complete crop. The selection of January is justified by two facts. Firstly, most of the trees in each plot yielded their maximum crop at this time, and secondly, it was found that such seasonal effects as appeared later were all in the direction of decreased values easily explained as due to the increasingly adverse growth conditions of the dry season as it advanced. As will appear, the values of the pod constants do not differ very greatly when the whole crop is taken into consideration from those calculated on the January pickings alone. It is reasonable to suppose that this will prove to be the rule in any normal year, and that it will be possible to assess the characteristics of a tree from the characters of the crop which it bears in its month of maximum yielding. This is important, because at the peak of yielding, the samples obtainable at a single picking are naturally greatest, and when an extended survey is commenced it will only be practicable to examine a single picking from any one tree.

From the January data, the mean, standard deviation and coefficient of variability of each dimension have been calculated for the ten trees giving the highest crop in three plots, and are presented in Tables 1 to 3.

In Table 4, the same constants determined from the complete data are presented for one plot (Caura) alongside the January figures, and the smallness of the differences is clearly brought out. The several characters will now be discussed separately, and the effects of season afterwards.

Length of pod.—The frequency curves for mean pod length in the three plots over the whole crop are given in Fig. 1, the data being grouped to the

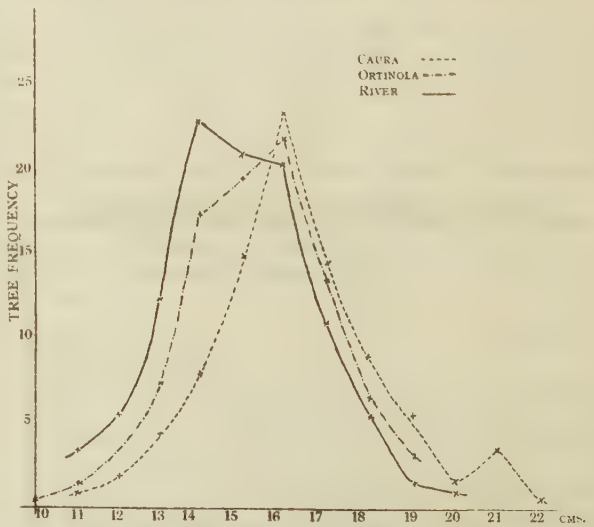


FIG. 1.—*Frequency Curve for Mean Pod Length.*

* Measurement of rate of development of cacao pods. Year Book, 1928, *Department of Agriculture*, Gold Coast (Bulletin 16), 1929, 121-27.

Table 1.

POD DIMENSIONS ON PLOT A.

	Tree.	1	2	3	4	5	6	7	8	9	10	Mean.
	Size of Sample.	37	26	99	31	47	54	75	49	48	151	
Length	M.	15.38	15.71	14.41	12.02	15.22	16.14	15.70	13.53	16.26	12.34	
	S.D.	1.07	1.41	1.32	1.34	1.06	1.24	0.99	1.40	0.91	0.86	
	C.V.	6.96	8.99	9.14	11.11	6.94	7.70	6.32	10.36	5.57	6.99	8.00
	N.	7.75	12.92	13.37	19.75	7.71	9.49	6.39	17.17	4.96	7.82	10.73
Diameter	M.	7.87	7.60	7.32	7.64	7.73	7.57	7.05	7.21	7.51	7.19	
	S.D.	0.49	0.57	0.59	0.68	0.55	0.57	0.47	0.62	0.57	0.44	
	C.V.	6.21	7.45	8.02	8.85	7.14	7.53	6.64	8.65	7.54	6.14	7.42
	N.	6.18	8.87	10.29	12.53	8.16	9.07	7.05	11.97	9.10	6.03	8.93
Thickness	M.	1.16	1.25	1.25	1.40	1.28	1.51	1.05	1.26	1.25	1.10	
	S.D.	0.13	0.16	0.16	0.16	0.14	0.16	0.15	0.17	0.16	0.14	
	C.V.	11.20	12.64	12.48	11.71	9.53	10.47	14.27	13.81	12.96	12.55	12.16
	N.	20.08	25.57	24.92	21.96	14.53	17.52	32.58	30.51	26.87	25.20	23.97

Table 2.

POD DIMENSIONS ON PLOT B.

	Tree.	1	2	3	4	5	6	7	8	9	10	Mean.
	Size of Sample.	34	26	27	33	76	25	43	53	25	88	
Length	M.	19.00	16.12	16.00	14.95	15.00	13.50	16.98	17.04	13.34	16.13	
	S.D.	1.95	1.68	1.12	1.61	1.71	1.11	2.02	1.55	1.36	1.51	
	C.V.	10.25	10.42	7.01	10.76	11.39	8.19	11.92	9.08	10.21	9.36	9.86
	N.	16.81	17.37	7.86	18.52	20.75	10.76	22.66	13.19	13.64	14.02	15.86
Diameter	M.	9.01	8.26	8.39	8.48	8.74	8.38	7.50	7.44	7.68	8.40	
	S.D.	0.92	0.76	0.20	0.62	0.91	0.71	0.98	0.63	0.58	0.70	
	C.V.	10.21	9.14	2.38	7.36	10.40	8.52	12.76	8.48	7.53	8.36	8.51
	N.	16.68	13.37	0.90	8.67	17.30	11.61	26.05	11.51	9.07	11.18	12.63
Thickness	M.	2.08	1.77	1.54	2.00	1.87	1.75	1.51	1.52	1.55	1.76	
	S.D.	0.37	0.28	0.21	0.19	0.25	0.31	0.21	0.20	0.21	0.29	
	C.V.	17.69	15.54	13.77	9.25	13.53	17.88	13.91	13.61	13.55	16.19	14.45
	N.	50.07	38.64	30.33	13.69	29.16	51.26	30.91	27.71	29.40	41.99	34.32

Table 3.

POD DIMENSIONS ON PLOT C.

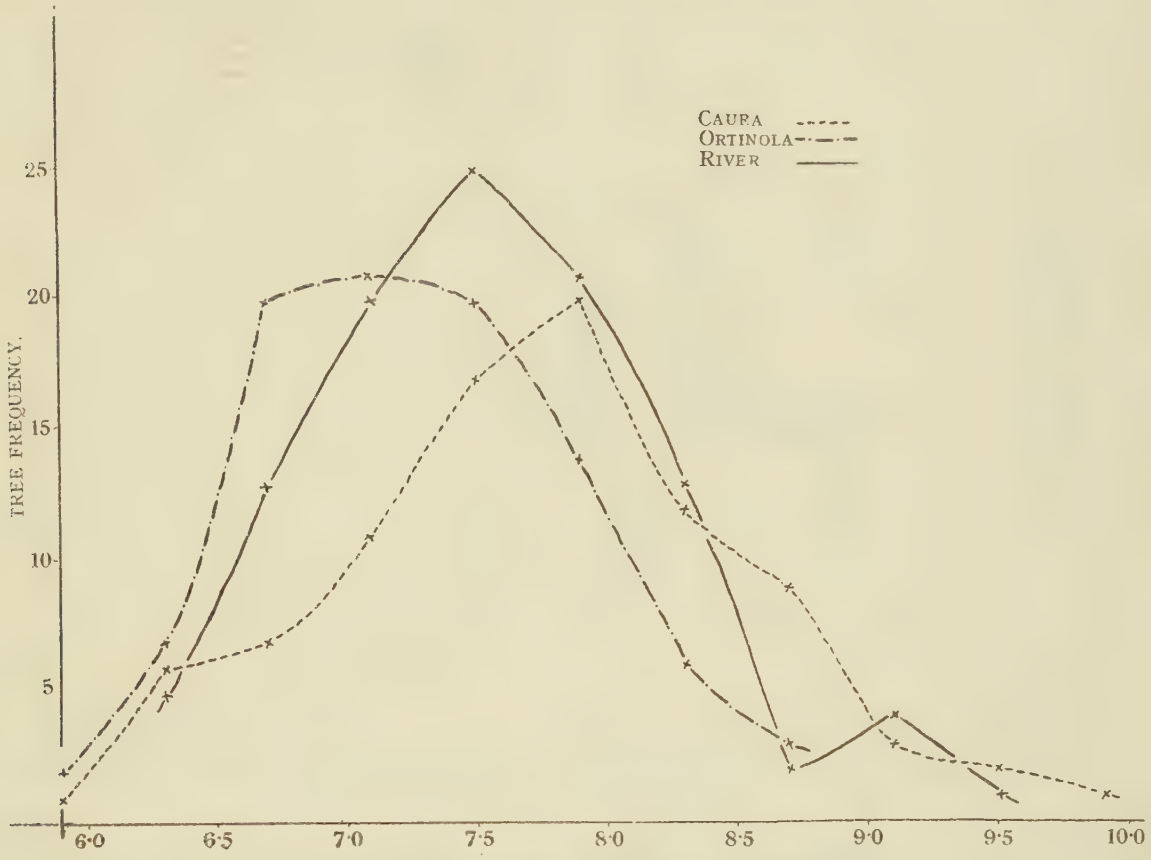
Tree.		1	2	3	4	5	6	7	8	9	10	Mean.
Size of Sample		77	23	30	25	28	39	24	44	20	44	
Length	M.	16.54	16.22	15.28	15.00	14.55	14.30	13.54	15.05	15.47	14.37	
	S.D.	1.03	1.68	1.62	1.24	1.12	0.95	1.27	1.19	2.05	1.25	
	C.V.	6.23	10.36	10.60	8.25	7.66	6.63	9.37	7.92	13.24	8.86	8.89
	N.	6.21	17.17	17.92	10.89	9.39	7.03	14.05	10.04	28.05	12.05	13.28
Diameter	M.	7.35	7.82	7.55	8.38	8.19	7.57	6.38	8.27	8.34	7.42	
	S.D.	0.52	0.85	0.77	0.79	0.58	0.47	0.61	0.48	0.76	0.62	
	C.V.	7.01	12.17	10.25	9.45	7.07	6.25	9.62	5.85	9.09	8.38	8.51
	N.	7.86	23.69	16.80	14.26	8.00	6.25	14.81	5.48	13.22	11.24	12.16
Thickness	M.	1.18	1.33	1.30	1.42	1.43	1.31	1.13	1.29	1.48	1.34	
	S.D.	0.17	0.20	0.20	0.15	0.17	0.16	0.21	0.16	0.29	0.21	
	C.V.	14.58	15.33	15.69	10.21	11.54	12.06	18.14	12.71	19.80	15.60	14.57
	N.	34.51	37.60	39.44	16.64	21.30	23.43	52.64	25.81	62.72	38.94	35.30

Table 4.

COMPARISON OF DIMENSIONS FOR JANUARY PICKING AND TOTAL CROP (CAURA).

	JANUARY.		TOTAL.		JANUARY.		TOTAL.		JANUARY.		TOTAL.	
Tree.	Mean Length.	S.D.	Mean Length.	S.D.	Mean Diameter.	S.D.	Mean Diameter.	S.D.	Mean Thickness.	S.D.	Mean Thickness.	S.D.
2	19.00	1.95	19.00	1.96	9.01	0.92	8.65	0.92	2.08	0.37	1.89	0.34
3	16.12	1.68	12.32	1.15	8.26	0.75	8.18	0.61	1.77	0.27	1.67	0.27
10	16.00	1.12	15.46	1.34	8.39	0.20	8.07	0.72	1.54	0.21	1.46	0.24
25	14.95	1.61	14.65	1.81	8.48	0.63	8.00	0.79	2.00	0.19	1.70	0.28
33	15.00	1.71	15.00	1.71	8.74	0.91	8.74	0.91	1.87	0.25	1.87	0.25
35	13.50	1.11	13.87	1.46	8.38	0.71	8.28	0.74	1.75	0.31	1.63	0.31
102	16.98	2.02	17.71	2.35	7.50	0.96	7.66	0.80	1.51	0.21	1.53	0.22
62	17.04	1.55	17.07	1.55	7.44	0.63	7.47	0.61	1.52	0.20	1.50	0.22
45	13.34	1.36	12.85	1.55	7.68	0.58	7.25	0.79	1.55	0.21	1.44	0.25
51	16.13	1.51	15.84	1.84	8.40	0.70	8.26	0.78	1.76	0.29	1.67	0.29
Mean	15.81	1.56	15.38	1.67	8.23	0.70	8.06	0.78	1.74	0.25	1.64	0.27

Length.		Diameter.		Thickness.	
"N." J.	"N." T.	"N." J.	"N." T.	"N." J.	"N." T.
15.59	18.80	11.56	14.93	33.18	43.52



II.—*Frequency Curve for Mean Pod Diameter.*

nearest centimetre. The range is from 10 to 22 cms., but the trees with very long or very short pods are relatively few, and all the curves rise steeply to the mode and fall steeply beyond it. The curve for the Caura plot is particularly symmetrical, and the difference between the other two will be discussed below. It may be noted here that the Caura trees lead in all three dimensions. The conclusion from general observations is that the slightly larger pods at Caura result from factors in the habitat rather than from genetic differences. In any case, the difference is very slight.

From Tables 1 to 3 it is seen that the coefficient of variability is strikingly similar for all the plots. It varies very widely from tree to tree within the plots and without respect to size of sample. It would therefore seem that some trees are inherently more variable in the length of their pods than others.

Diameter.—From Tables 1 to 3 it appears that the diameter of the pod is in general slightly less variable than the length. Also, in general, the trees which are most variable in the length of their pods are also the most variable in diameter. Fig. 2 shows the frequency curves for the whole crop. Their most interesting feature is that the relative positions of the River Estate and Ortinola curves are the reverse of those in Fig. 1. This, of course, implies a difference in pod shape between the two plots, those of the Ortinola plot being rather longer and narrower than those at River Estate. A superficial examination of the trees themselves is sufficient to show that there is a

FIG. III.—*Frequency Curve for Mean Shell Thickness.*

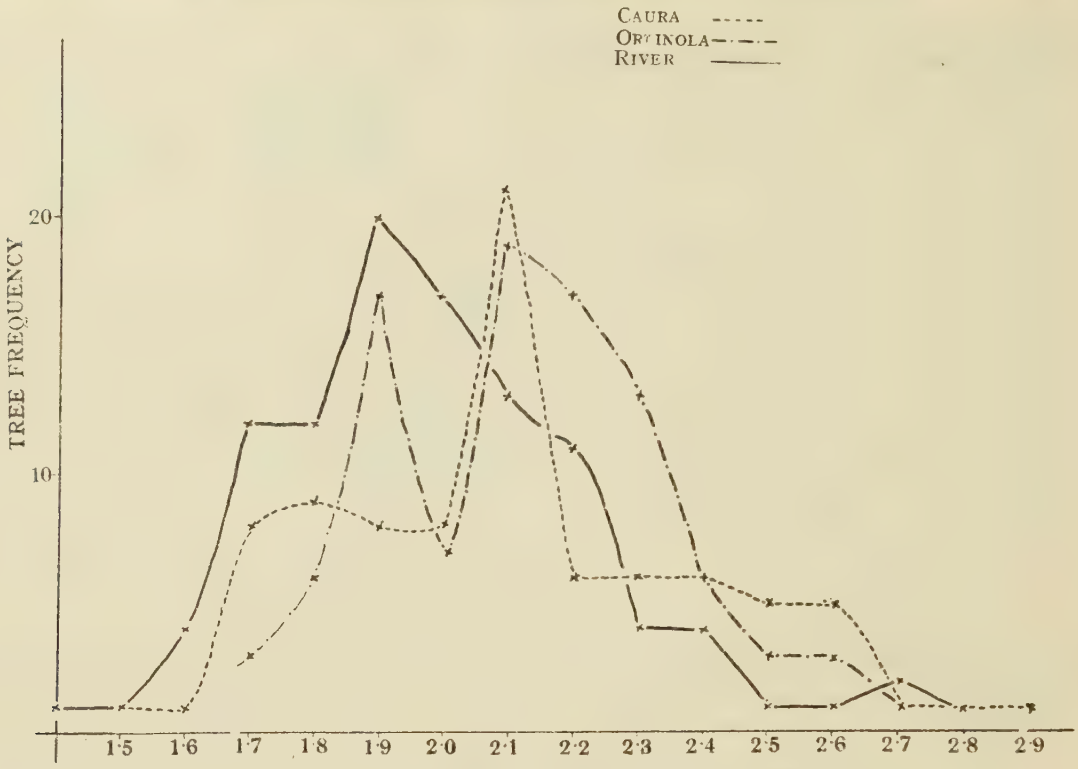


FIG. IV.—*Frequency Curve for Mean Pod Ratio.*

higher proportion of Angoleta and Cundeamor type pods in the Ortinola field than in the other, and this genetic difference completely explains the nature of the graphs.

Shell Thickness.—The distribution of mean shell thickness is shown in Fig. 3. It is noteworthy that the mean thickness at Caura is rather greater than that at River Estate or Ortinola, and this is evidently another expression of the physiological vigour which has already been noted as responsible for slightly larger pods. The other curves almost coincide, and the great majority of pods from River and Ortinola have a mean shell thickness between 10 and 14 mm. Tables 1-3 show that this character is markedly more variable than either length or diameter.

Pod Shape.—The distribution of pod shape (Fig. 4) (calculated as explained above as L/D) is interesting. The Ortinola curve has two peaks which coincide exactly with the modes for River (1.9) and Caura (2.1). When the three are added together (Fig. 5), the bimodal nature of the curve is of course accentuated. This seems to suggest that the population examined contains two populations distinct with respect to pod ratio, each with its own characteristic mode. No conclusion, however, can be drawn with any confidence, because of the possibility that with additional data from other estates the dip in the graph at 2.0 may fill up.

The Effect of Season.

The effect of season on length is partly shown in Table 4, where the mean difference between the whole crop and the January picking is less than 3 per cent. When the mean length in July alone was compared with the mean length in January, the difference was found to be 9.55 per cent. of the January value. The decrease in magnitude is accompanied by a rise in variability, as shown by σ, but this is very slight.

Diameter is rather more affected by season than length. This point is not brought out in Table 4, but the difference between the mean diameters in July and those in January was found on the whole data to be 13.79 per cent. of the January value.

Since the differences are in both cases decreases with increasing dryness of weather, it follows that one of the seasonal effects must be a change in pod shape, those fruits maturing in July being narrower relative to their length (or longer relative to their diameters) than those maturing in January. The variance of the ratio of mean length to mean diameter was analysed for 24 trees at Caura, which gave a crop at each of the seven pickings from January to July, as follows :—

Analysis of Variance.

Due to	D.F.	Sum of Squares.	Mean Square.	$\frac{1}{2}$ Log$_e$.
Between pickings	6	28	4.7	0.7738
Between trees ..	23	984	42.8	1.8783
Error ..	138	128	0.93	$\bar{1}$.9637
Total ..	167	1,140		

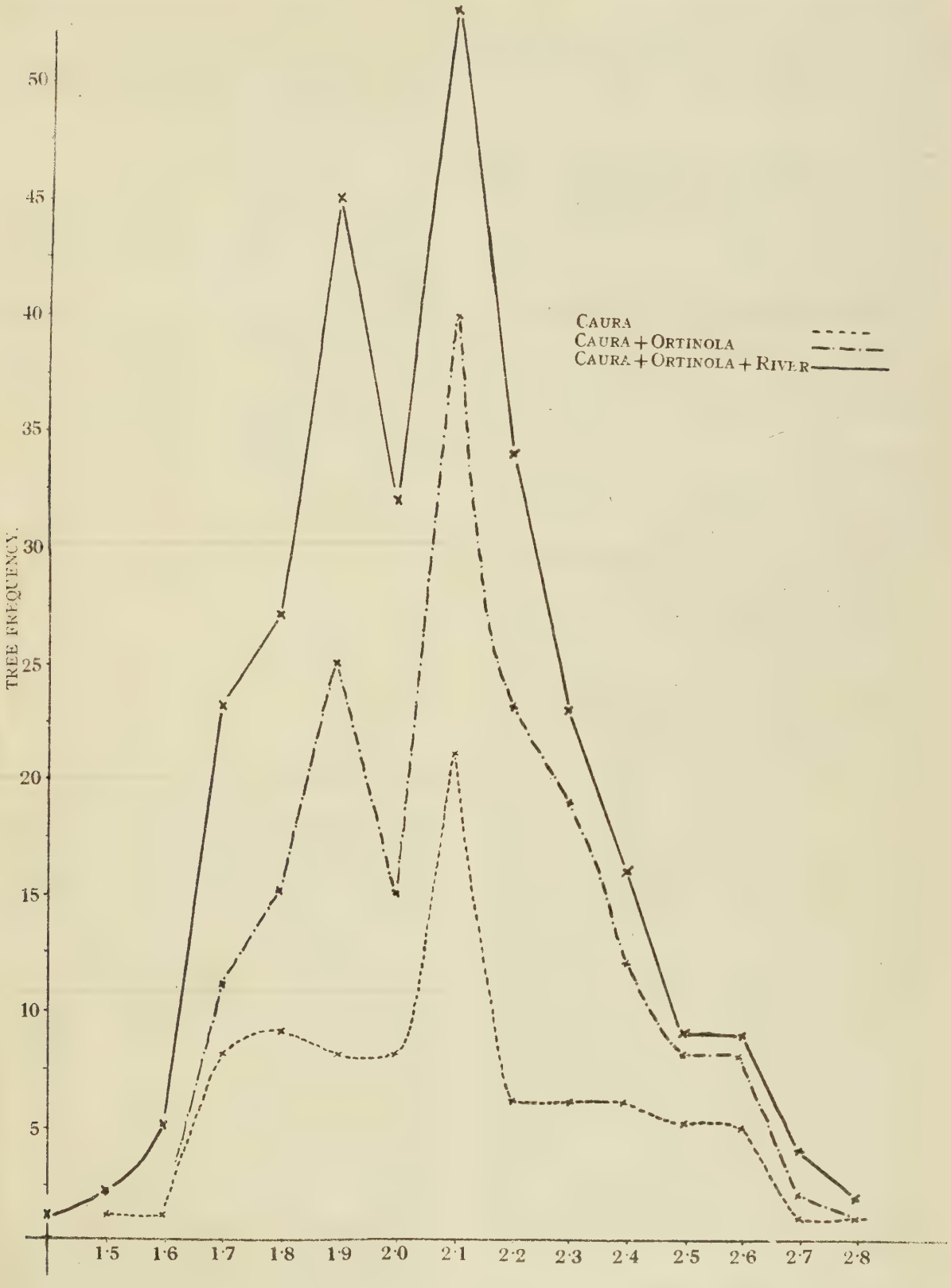


FIG. V.—*Mean Pod Ratio added by Plots.*

The variance between trees is great, but no more than might be expected, as the fact that pods of different trees have significantly different shapes is known by general observations. The variance between pickings is the point of interest, and although much smaller, it also proves to be significant.

At the same time as the pods become narrower, they also become thinner shelled, and the analysis of variance of shell thickness within and between pickings shows that the mean square due to season is almost as great as that due to genetic differences between trees.

Analysis of Variance of Shell Thickness.

Due to	D.F.	Sum of Squares.	Mean Square.	$\frac{1}{2}$ Log_e.
Between trees ..	23	698.5	30.4	1.7072
Between pickings	6	167.6	27.9	1.6643
Interactions ..	138	313.3	2.27	0.4099
Total ..	167	1,179.4		

The full difference between the means for July and January was found to amount to a decrease with the advancing drought, of 3.6 mm., or almost 27 per cent. of the January value. Table 4 shows that even when the whole crop is compared with the January picking the difference is 16 per cent., which is very much more than the differences exhibited by either length or diameter.

It may be added, although the data are not yet complete, that another effect of the dry season is a reduction in the mean weight of the single bean, which will probably prove to be more striking than any of those reported above. Many trees in July gave beans weighing on the average less than one gramme, whereas the average in January and February is believed to be about three grammes.

On all counts, therefore, the economic significance of further studies of seasonal fluctuations can hardly be overestimated. It appears that the earlier the main crop comes with reference to the dry season, the bigger it must be on grounds of size of pod and the better its quality with respect to size of bean. Physiological studies will perhaps reveal methods of hastening crop, but on the genetic side there is a clear advantage to be gained by selection for earliness, other factors being equal. There are, of course, many other factors, some pathological and some economic, which help to determine the optimum time for the peak of the crop, but those are not within the scope of this discussion.

The Effect of Position.

Towards the end of the season it was decided to test whether significant differences occur between pods borne in different positions on the tree. The results presented are preliminary, and will be supplemented later by figures for the earlier part of a season.

A number of trees were each divided by strips of coloured oilcloth tied round the trunk and branches into three zones, viz. :—

A.—The main trunk.
B.—The main branches.
C.—The finer branches.

The three zones were picked separately, and the mean dimensions calculated separately for each zone. The number of trees which gave a sufficient crop in each zone to warrant analysis was seventeen.

The length of pod was found to decrease significantly from zone A to zone C, the total of the zonal means for the 17 trees being :— A 265.9 ; B 253.0 ; C 240.2. A minus C is 9.67 per cent. of A. That this is significant is shown by the analysis of variance, in which the mean square due to position proves larger than that due to genetic differences between the trees used :—

Analysis of Variance of Pod Length.
(In cm.)

Due to	D.F.	Sum of Squares.	Mean Square.
Between trees ..	16	136.2	8.5
Between zones ..	2	20.0	10.0
Interactions ..	32	15.9	0.5
Total ..	50	172.1	

Similarly, the diameter decreases from A to C, and proportionately rather more than the length. The totals of the zonal means were :—A 136.1 ; B 128.8 ; C 119.6. A minus C is 12.1 per cent. of A. Significance is proved by analysis of variance :—

Analysis of Variance of Diameter.
(In mm.)

Due to	D.F.	Sum of Squares.	Mean Square.
Between trees ..	16	1,984.9	124.1
Between zones ..	2	804.4	402.2
Interactions ..	32	1,391.0	43.5
Total ..	50	3,180.3	

Since diameter decreases more than length, there must be a change in shape, which is expressed by an increase in the ratio L/D. Totals of zonal means for this ratio were :—A 33.1 ; B 33.5 ; C 34.4. The difference is about 4 per cent. of A, and is significant.

Analysis of Variance of Pod Ratio.

Due to	D.F.	Sum of Squares.	Mean Square.	$\frac{1}{2}$ Log$_e$.
Between trees ..	16	205.0	12.8	1.2747
Between zones ..	2	5.2	2.6	0.4778
Interactions ..	32	16.0	0.5	1.6533
Total ..	50	226.2		

For shell thickness the totals of zonal means were :—A 24.8 ; B 22.8 ; C 20.8. A minus C is 16.6 per cent. of A.

Analysis of Variance of Shell Thickness.

Due to	D.F.	Sum of Squares.	Mean Square.
Between trees ..	16	176.4	11.0
Between zones ..	2	47.1	23.6
Interactions ..	32	40.9	1.28
Total ..	50	264.4	

The effect of position is strikingly similar to that of season, even to the magnitude of the differences in some cases, "A minus C" corresponding to "January minus July" values. This, of course, is only in accordance with a physiological principle which was in mind when the test was made, and which is expressed in many species by more xeromorphic characters of the upper leaves as compared with the lower. Nevertheless, it is interesting to have the statistical demonstration of its operation in cacao pods, and figures will subsequently be given for bean number and bean weight. If a pod on the trunk is consistently worth more cacao than one on a branch, another guiding line can be laid down for selection to utilize such differences in bearing habit as occur, and for manipulation to change habit, subject, of course, to the many and complex considerations which bear on final yield.

The Size of Sample.

One of the main objects of the season's work was to determine the number of pods which must be measured in order to characterise an individual tree, for when a genetic survey is undertaken the amount of time to be spent on single trees must necessarily be reduced to a minimum. The standard of accuracy desired is within 5 per cent. with P=0.05. That is to say, the mean of the sample taken should be within 5 per cent. of the true mean for the tree ninety-five times out of a hundred. The appropriate size of sample is readily determinable from the constants of the normal curve of errors. If the mean of the population is M and the Standard Deviation σ, the Standard Error of the mean of a sample of "n" observations is $\frac{\sigma}{\sqrt{n}}$, and if repeated samples of "n" observations are taken, their means will fall within the limits $M \pm \frac{2\sigma}{\sqrt{n}}$ in rather more than 95 per cent. of cases.

We require then that $\frac{2\sigma}{\sqrt{n}}$ shall not be more than .05M, whence "n" must not be less than $0.16 \left(\frac{100\sigma}{M}\right)^2$. Otherwise expressed, the required sample number is not less than 0.16 times the square of the coefficient of variability, expressed as a percentage. In Tables 1-3 the "n" gives the values of this quantity for each case.

It will be noted that for length and diameter the average value of "n" is less than 20, and the maximum below 30. Shell thickness is rather more variable, which is due to its variation with degree of ripeness of the pod. Consequently, a sample of 30 pods will not give a mean accurate within 5 per cent. Thickness is, however, a factor of minor importance, and it appears better to relax a little on precision in this one respect than to increase the number of measurements. The maximum error will rarely exceed 10 per cent. of the true mean, and it has been decided that 30 pods shall form the standard sample in future work. From such figures as are yet available it appears probable that the same number will give a satisfactory estimate of bean weight ; if it does not, some modification may be found necessary.

The "true mean" to which the sample mean approximates is, of course, the mean of a hypothetical infinite crop gathered at *one picking*. Table 4 shows that if that picking is taken at the time of heaviest crop, its mean approximates very closely to that for the whole crop from the tree. Additional errors would be introduced by sampling late in the season, but for the practical reason that adequate samples would be available on very few trees at that time, this objection need not concern us. Within reasonable limits we may conclude, however, that little accuracy will be lost by bulking small samples from successive pickings in cases where less than the standard number of pods are available at any one time.

Correlations.

The constancy of the pod ratio L/D used as an index of shape, indicates a strong correlation between length and diameter of the pods from any one tree. There is some variation with season and with position, but the extent of this has been discussed above, and needs no further treatment.

The correlation of shell thickness with size has been calculated for two heavy bearers, and found to be positive in each case. Thus, for tree 25 (Caura), r=0.685 (n=150), and for tree 45, r=0.555 (n=128). These coefficients could be obtained by chance in a fraction of 1 per cent. of cases.

Summary for Pod Dimensions.

1. The greatest variability in cacao pod dimensions is that between different trees.

2. The variability between pods of one and the same tree is large, but a random sample of thirty pods is sufficient to characterise the tree, giving means for length and diameter accurate within 5 per cent. and for shell thickness with slightly less precision.

3. The seasonal variability is also large, but estimates based on samples taken at the time of maximum bearing are very close to the means for the whole crop.

4. The seasonal variability takes the form of a reduction in all dimensions which is progressive with the course of the dry season, and is accompanied by a slight change in shape.

5. Pods on upper and outer branches bear a relation to those at the base of the tree similar to that between pods ripening towards the end of the dry season and those ripening at its commencement.

Statistics of Bean Number.

The variability of bean number proved to be much greater than that of the linear dimensions, and examination of the frequency curve showed that this was correlated with marked asymmetry, the deviations below the modal number being far more numerous than those above. This suggested incomplete development of potential seeds, and led to enquiry into the variability of ovule number per ovary in the flower, and subsequently into consideration of discrepancies between the two quantities.

Variability of Bean Number.

To take first the facts concerning the number of beans per pod, Fig. 6 shows the frequency distribution of mean bean numbers, grouped to multiples of five, for the whole crop on the three plots separately. The modes all coincide at 35, and the only marked departure from symmetry is in the case of the curve for the Caura plot, where an unexpectedly high proportion of the trees have a mean of only 30. Read in conjunction with the fact that pod dimensions on this plot were all slightly higher than elsewhere, the result is rather surprising, and suggests that there may be a genetic reason, which cannot be specified at present.

The extreme range of mean bean number for the crop was from 15.5 to 47.5, which is wide, but the curves show that the tail below 25 is small, and the great majority of trees show values between 25 and 45. Even this range, however, is sufficiently wide to show that bean number must be a factor with very considerable influence on final yield.

The means, standard deviations and coefficients of variability for individual trees, calculated on the January picking are set out in Table 5, the trees used being the same as those employed for analysis of linear dimensions. From this table it is seen that not only is the mean coefficient of variability higher than for any of the dimensions, but the coefficients of individual trees vary more between themselves. Coefficients above 20 per cent., a value never reached even by shell thickness, the most variable of the

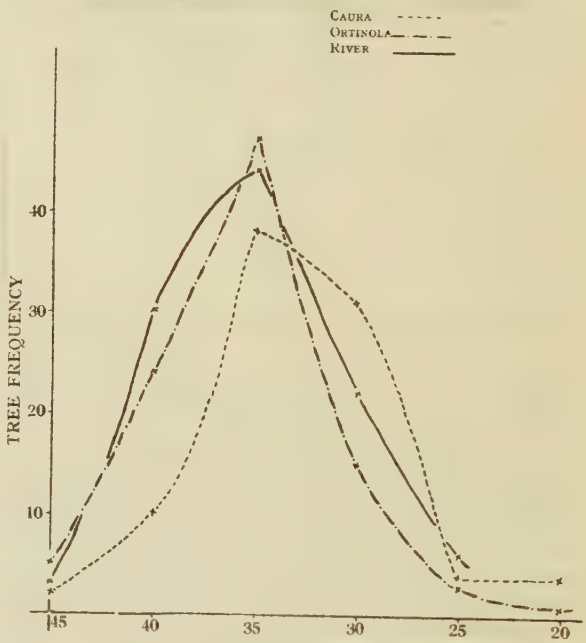


FIG. VI.—*Frequency Curve for Mean Bean Number.*

dimensions, occur in nine cases out of thirty, and the number of pods required as a sample to give a mean within 5 per cent. of the truth is above thirty in two-thirds of the cases, and above fifty in nearly half.

The practical conclusion from the values of n is that bean number is an unreliable quantity for characterisation of individual trees within the limits of practicable sampling, and from that point of view it must be dropped. On the other hand, the variability itself presents a problem which would appear to be an integral part of the analysis of yield, and must be explored more deeply. The first step is evidently to determine the variability of the ovules from which the seeds develop.

Ovule Frequency.

It was found that the ovules in the ovary of the open cacao flower can be satisfactorily counted by dissection under a binocular microscope.

The variability of ovule number in four trees taken at random was found to be :

Table of Ovules per Ovary.

No. of ovaries dissected ..	15	10	9	15
Mean No. of ovules per ovary ..	45.2	40.3	48.3	42.4
Standard Deviation ..	2.45	1.58	1.63	1.48
"n"	4.72	2.47	1.82	1.95

In marked contrast to the seeds in the ripe fruit the ovules are so constant in number that five ovaries are an adequate sample for estimation of the mean for a tree. The differences between trees are clearly significant, but between the pods of one and the same tree it is evident that variability in bean number does not arise from variability in ovule number.

Bean Number and Shape of Pod.

In the Caura plot it was noticed that the pods with a high length / diameter ratio produced significantly fewer beans than those with a low ratio. Thus twelve trees with a mean ratio of 2.5 or more gave a mean bean number of 28.8, whilst twelve with a mean ratio of 1.7 or less gave a mean bean number of 36.1. On analysis of variance :

Variance between classes = 314.2
Variance within classes = 49.3

showing the variance between classes to be much greater than that within classes, with significance greater than P=0.01.

On further analysis of variance within classes :

Variance between trees = 16.5
Variance of Interactions between trees and classes .. = 32.8

Table 5.

Bean Number on Plots A, B and C.

Plot.		A										Mean.
Size of Sample.		37	26	99	31	47	54	75	49	48	151	
No. Beans	M.	36.9	38.6	32.1	31.3	37.4	35.8	37.4	32.8	42.1	31.2	
	S.D.	3.22	3.48	2.04	8.77	2.92	4.06	5.60	7.51	4.29	4.67	
	C.V.	8.73	9.00	6.35	28.03	7.81	11.34	14.98	22.88	10.19	14.97	13.43
	N.	12.20	12.96	6.46	125.7	9.76	20.57	35.91	83.76	16.61	35.86	35.98

Plot.		B										Mean.
Size of Sample.		34	26	27	33	76	25	43	53	25	88	
No. Beans	M.	35.2	32.4	34.4	27.7	30.5	36.8	28.6	25.1	38.3	35.1	
	S.D.	9.36	8.06	4.02	9.40	7.58	4.34	6.76	5.98	7.58	6.76	
	C.V.	26.59	24.88	11.69	33.93	24.85	11.79	23.63	23.82	19.79	19.26	22.02
	N.	113.12	99.04	21.86	184.19	98.40	22.27	89.11	90.63	62.72	59.52	84.09

Plot.		C										Mean.
Size of Sample ..		77	23	30	25	28	39	24	44	20	44	
No. Beans	M.	34.2	31.5	32.2	40.0	36.6	39.6	35.5	39.4	33.7	36.7	
	S.D.	3.84	4.20	5.85	8.49	5.52	4.91	4.93	6.26	6.65	5.16	
	C.V.	11.22	13.33	18.16	21.22	15.07	12.41	13.87	15.89	19.73	14.08	15.50
	N.	20.07	28.32	52.77	72.05	36.34	24.64	30.78	40.40	62.10	31.72	39.92

Table 6.

OVULE FREQUENCY PER LOCULUS.

Tree.		45	48	58	84
a	Mean	9.48	8.60	10.16	9.60
	S.D.	0.6428	0.6325	0.5419	0.6110
	C.V.	6.781	7.355	5.334	6.365
b	Mean	9.04	8.60	9.80	9.40
	S.D.	0.7772	0.6325	0.4000	0.4899
	C.V.	8.597	7.355	4.082	5.212
c	Mean	8.36	8.24	9.48	9.16
	S.D.	0.4800	0.4271	0.6993	0.4620
	C.V.	5.742	5.183	7.377	5.044
Total	Mean	8.96	8.48	9.81	9.40
	S.D.	0.7941	0.5968	0.6261	0.56126
	C.V.	8.863	7.038	6.382	5.971
Diff. of Means					
(*a-b*)	.. .. ..	0.44	0.00	0.36	0.20
t cal :	.. .. ..	10.687	0.00	13.093	6.866
Diff. of Means					
(*b-c*)	.. .. ..	0.68	0.36	0.32	0.24
t cal :	.. .. ..	18.235	11.556	6.139	8.731
"*t*," n∞. P=.01	.. .. ..	2.576	2.576	2.576	2.576

so that although the variance between trees is small, it is not so small that the trees of one class are significantly identical.

The correlation between mean bean number and pod ratio is negative, r=—0.393 and the significance is greater than that denoted by P=0.01.

Results from the River Estate plot are similar. Trees with a mean ratio of 2.5 or more gave a mean bean number of 31.3, whilst those with a mean ratio of 1.7 or less gave a mean bean number of 37.0. The correlation has significance with a value lying between P=0.02 and P=0.01.

The Ortinola plot does not agree. It was pointed out in a previous section that the graph of ratio in this plot has well marked modes at 1.9 and 2.1. The mean bean number of trees with ratio below 2.0 was 35.4, and that of trees with a ratio above 2.0 was 35.5. Even the trees with pods of the extreme shapes gave practically equal bean numbers. This must be attributed to some difference in the genetic constitution of the Ortinola trees, which must remain for the present unexplained.

In the Caura plot, ovule counts were made on flowers taken in October, and allowing five months for pod development they should be directly comparable with the mean bean numbers for the January to June crop. The results show no correlation between ovule number and pod shape, and they are of further interest as illustrating the magnitude of the discrepancies which occur between the two counts.

	Trees with Mean Ratio above 2.6			Trees with Mean Ratio below 1.7.		
	Mean No. Ovules.	Mean No. Seeds.	Difference.	Mean No. Ovules.	Mean No. Seeds.	Difference.
	40	30	10	42	34	8
	47.5	28	19.5	38.5	33	5.5
	40	21	19	39	30	9
	44	32	12	46.5	44	2.5
	41	31	10	40.5	31	9.5
	52.5	34	18.5	50	40	10
Avg.	44.2	29.3	14.9	42.8	35.3	7.5

It is interesting to notice that among the trees with long and narrow pods the loss of ovules by failure to develop is roughly 25 per cent. in three cases and nearly 50 per cent. in three cases. Among the trees with relatively short broad pods the loss is of the order of 25 per cent. in four cases, and in the other two cases, very roughly half of that. The speculations which are raised as to the possible operation of lethal factors and incompatibility will appeal to geneticists, but cannot be discussed in this place.

Bean Number and Position of Tree.

The mean bean number in each of three zones of seventeen trees is set out below, the trees and zones being the same as those specified above.

Tree.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	Totals.
Mean Zone A	34	27	37	35	38	25	31	30	39	35	36	35	47	36	27	43	34	589
Do. B	38	31	35	32	40	25	29	32	36	37	31	32	37	37	34	41	38	581
Do. C	38	35	34	30	35	28	32	31	33	31	33	32	35	33	38	39	29	566

There is a slight progressive decrease in the zonal totals from A to C, equal to 3.9 per cent. of the value for A. Examination tree by tree, however, shows a regular *increase* from A to C in four cases (1, 2, 6 and 15) and the increase is significant.

Zonal Totals.

A	113
B	128
C	139

Analysis of Variance.

Due to	D.F.	Sum of Squares.	Mean Square.
Between trees ..	3	178.0	59.3
Between zones ..	2	85.2	42.6
Interactions ..	6	25.5	4.25
Total ..	11	288.7	

Six trees show a significant decrease (3, 4, 9, 12, 13, 16) and the remainder waver. The analysis of variance for the six is :—

Analysis of Variance.

Due to	D.F.	Sum of Squares.	Mean Square.
Between trees ..	5	183.1	36.6
Between zones ..	2	95.4	47.4
Interactions ..	10	36.6	3.7
Total ..	17	315.1	

These figures appear to indicate a conflict in the crop as a whole between two opposite tendencies. In passing it may be remarked that in both cases, when the lengths and diameters of the pods concerned are examined zone by zone, there is a significant and progressive lowering of the dimensions from zone A to zone C. In the case where bean number *increases* in that direction it may therefore be concluded that the number of beans in the pod is without influence on the size of the pod, or at least that it is not a major controlling factor.

Investigations of ovule number have so far failed to produce any evidence of similar systematic changes with position in more than one direction. Ovaries from three zones on four mature trees were examined in June, and the ovule counts are given in Table 6. Except in the one case of zones A and B on tree No. 2, there is a significant *decrease* from any zone to the next above on the same tree. Later, two of the trees which showed an increase for bean number from A to C were examined for ovule numbers and the results (per loculus) were :

A	8.78	8.72
B	9.28	8.88
C	9.20	8.72

At the same time two trees with a well marked *decrease* in bean number from A to C were examined for comparison and gave the following figures :

A	8.44	8.32
B	8.44	8.24
C	8.28	8.30

There is no marked trend in either direction in either case. Nothing further can be said at present, but the question of variability in ovule number is being investigated further, as an essential preliminary to any understanding of the bean frequencies.

Conclusions.

In contrast to the number of beans, which is markedly variable from pod to pod, the number of ovules is found to be remarkedly constant from ovary to ovary on any one tree.

The discrepancy between the number of ovules in the ovary and the number which successfully mature into seeds is very great. The loss is frequently of the order of 25 per cent., and sometimes nearly 50 per cent.

Among possible causes of loss, incomplete pollination, the operation of lethal factors, and physiological conditions, have all to be considered.

The fact that the loss is not constant from pod to pod suggests that purely genetic factors are not entirely responsible. On the other hand, significant differences in the percentage loss between classes of pods grouped according to shape, strongly suggest genetic factors, as the differences in shape are themselves largely the expression of differences in ancestry.

The results of observations to date are presented for the sake of the wide fields of research which they open up and it is fully realized how

fragmentary they are. At the same time, they are sufficient to indicate that further investigations of bean number, ovule number and the discrepancies between them are likely to prove very profitable.

In conclusion, acknowledgment is due to a paper on "The Improvement of Yield of Sea Island Cotton in the West Indies by Isolation of Pure Strains" by S. C. Harland in the *West Indian Bulletin* 17, 1919, pp. 145-161, which deals among other subjects with the discrepancy between ovule number and seed number in certain strains of cotton, and inspired the application of similar methods to cacao when the wide fluctuations of bean number were first observed.

* * *

STUDIES OF FRUITFULNESS IN CACAO.

I.—A Note on the Abscission of the Flower.

By F. J. Pound, B.Sc.

In the course of general observations on the behaviour of cacao trees during the past year, it was noticed that the flowers produced during the dry season, particularly in May, rarely remained attached to the trees during the second day, while unpollinated flowers produced in September were quite frequently found attached even on the morning of the third day. Bearing in mind that the dry season flowers rarely set fruit there may be some mechanism in the flower abscission which plays a major role in fruit setting.

The flower pedicel breaks at a point about 1 mm. from the base (Fig. 7) where on examination there proves to be a constriction of the tissues.

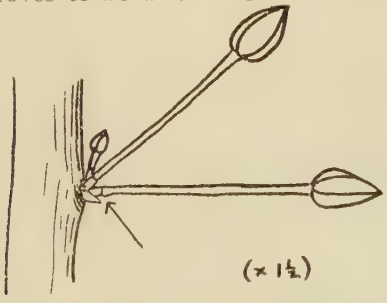


Fig. VII.—*Sketch of Young Cushion showing Buds. The arrow indicates position of constriction at base of pedicel.*

The appearance of this constriction in the young flower bud about 3 mm. long (Fig. 8) suggests, that it coincides with the base of the receptacle and that the apparent pedicel of the fully developed flower is to be regarded as mainly an elongated receptacle.

The actual tissues around this region in the mature bud are shown in Fig. 9. It cannot fail to be noticed that the constriction is concerned entirely with cortical tissue since it is almost possible to follow each row of cortical cells below, as they pass the constriction and continue into the cortex above.

At the base of the groove the cortical cells are small, they have dense contents and may be meristematic. On either side the cells are large, thin-walled and parenchymatous. The theory of abscission advanced is that as the bud matures and the flower opens, manufactured foods are passed into the pedicel, since at that time there is abundant starch in the tissues. If fertilisation takes place and the pistil continues to grow, a good deal of respirable material is removed. If no pollination takes place and this respirable material is not used, its accumulation in the pedicel sets up a high osmotic pressure in the large cells about the constriction. The pressure which results between the two "rims" of cortical tissue is sufficient to rupture the cells of the bundle, and the flower is severed.

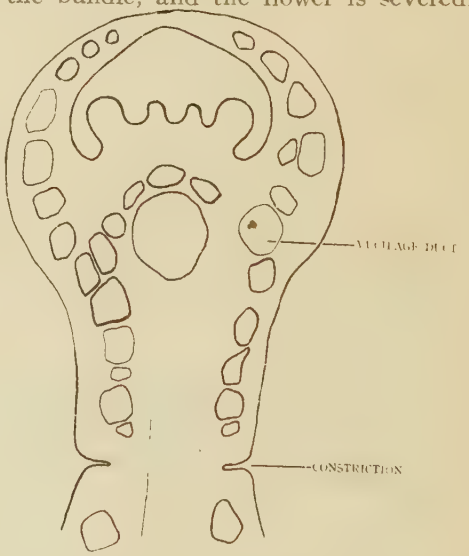


Fig. VIII.—*Longitudinal Section of very young Bud showing the main mucilage ducts and the constriction of the pedicel.*

The evidence in support of the theory is all indirect, but it does point to some mechanism of abscission which if not identical with, must be very similar to, that suggested.

(1) If a cacao tree in flower is visited early on a still morning a good number of the flowers which were open on the previous day will fall at the slightest shock. Those which fall in this way show a distinct swollen rim of tissue around the outside and usually a few torn tracheids can be found in the centre. Freshly opened flowers can be flicked very severely but still they do not fall.

(2) Flowers which have been covered with a two-inch specimen tube, sealed air-tight with plasticine, fall much more quickly than control flowers left uncovered. The effect of covering

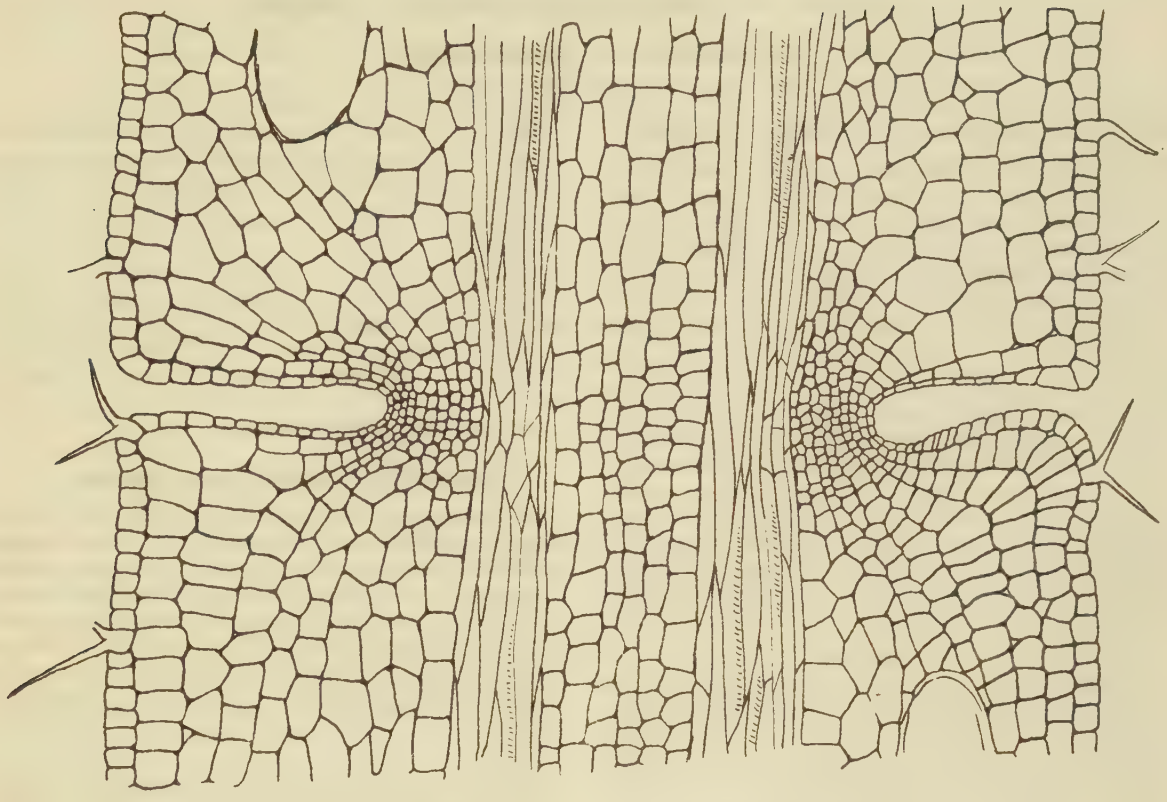


FIG. IX.—*Longitudinal Section of mature Bud at region of constriction. Note the large cortical cells at the shoulders.*

will have been largely to retard transpiration and to a certain extent respiration. The retarded transpiration would tend to develop a large turgor in the cells about the constriction and this would aid abscission. The retarded respiration if at all appreciable, would supplement the same reaction by preventing the removal of osmotically active materials from this region.

(3) Flowers on a cut branch always wilt. The water lost by transpiration is not replaced and the turgor of the cells of the pedicel is reduced so that no abscission takes place.

(4) If a flower head or bud head is severed, leaving the pedicel still attached to the twig, abscission of the remaining portion of the pedicel often occurs within a few hours. The removal of the flower head doubtless has a similar effect to the placing of a specimen tube over it, and the abscission follows the retarded transpiration, and perhaps respiration.

If it can be accepted from these observations that there is an osmotic mechanism responsible for and controlling flower abscission it is possible to advance several suggestions for the failure of the May and June flowers to set fruit. During the latter part of the dry season comparatively little crop is being removed from the trees and during this period new canopies are added. The rate of assimilation of food materials must be fairly high, despite the adverse conditions, for the cushions and twigs are full of starch.

The generally high concentration of osmotically active materials would tend in accordance with the theory to cause flowers to fall rather more early than normally. At the same time, it is quite possible that the osmotic concentration of materials in the stylar tissues may not be favourable for pollen tube growth. This is supported by plate experiments where pollen tubes grew most rapidly in a medium of 10 per cent. sucrose (1.5 per cent. agar agar) but in media of higher or lower concentrations of sucrose the rate of growth was less. The optimum concentration in the style will not be the same as the optimum *in vitro*, but similar relations are likely to obtain in the two cases.

If pollination or fertilisation is responsible for the inhibition of the abscission mechanism then slowly growing pollen tubes would not have as pronounced an effect as rapidly growing ones, since if the inhibition is a question of the using up of respirable materials then rapidly growing pollen tubes will aid in this respect, and, by causing early fertilisation and resumed growth of the ovary will result in a bigger drain on the soluble carbohydrates of the pedicel.

Summary.

1. The morphology of the pedicel suggests that flower abscission takes place at the constricted region by an osmotic mechanism.

2. A number of indirect observations support this theory.

3. If it is correct then some light is thrown on the reason for the failure of May and June flowers to set fruit.

STUDIES OF FRUITFULNESS IN CACAO.

II.—Evidence for Partial Sterility.

By F. J. Pound, B.Sc.

The Number of Ovules in Wilting Cherelles.*

The wilting and subsequent loss of young fruit is of vital importance to the cacao crop, and there is no doubt that weather conditions play a large part in it, for there seems to be always a large amount of wilting in years when there is no fine spell in October.

Apart from this it is quite obvious in the field that some trees lose much more fruit in this manner than others and the extreme cases are not infrequent where large numbers of cherelles set but practically none mature.

This has led to the suggestion that wilting may be due to incomplete pollination or to incompatibility. The latter cause is certainly suggested when Rounce and Smart (1) find the maximum wilting occurs at the same time after setting as Cheesman (2) finds the first division of the zygote takes place.

If wilting is due to incomplete pollination we should expect to find fewer ovules in wilting cherelles 2 inches in length than in sound cherelles of the same size, for it is improbable that ovules would grow to a diameter of two or more millimetres if they were unpollinated.

With this idea in mind the writer took 15 trees at River Estate which were bearing both sound and wilting cherelles. Five to eight of each kind, approximately 2 inches in length were taken at random from each tree. They were dissected and the ovules counted. The mean number of potential beans for each tree is set out in the table below.

Table of Ovule Counts.

Cherelles 5-9 cms. long.

(Means per tree. 5-8 of each. Equal numbers good and bad from each tree.)

	Wilting.	Good.	Diff.
1	34.8	34.4	−0.4
2	39.7	35.3	−4.4
3	32.7	35.1	+2.4
4	40.0	40.3	+0.3
5	38.0	39.1	+1.1
6	34.0	33.0	−1.0
7	37.5	37.1	−0.4
8	32.3	35.6	+3.3
9	37.8	37.7	−0.1
10	43.0	42.0	−1.0
11	46.6	46.2	−0.4
12	42.5	42.8	+0.3
13	36.7	35.3	−1.4
14	45.3	44.2	−1.1
15	45.6	43.8	−1.8
Total	586.5	581.9	..
Average	39.1	38.8	..

* Young fruits 2 to 3 inches long.

The difference between the mean number of ovules in sound and in wilting cherelles is sometimes positive and sometimes negative. In no case is the difference large enough to suggest significance.

The averages over the 15 trees come very close together being 39.1 for the wilting cherelles and 38.8 for the sound cherelles. From these figures there are certainly no grounds for assuming that the cherelles which wilt are those which were only partially pollinated.

Hand Pollination of Clonal Material.

If wilting is at all dependent on genetic incompatibility then apparently that incompatibility is not expressed until the zygote should commence to grow. With a view to studying the amount of incompatibility which may exist in cacao, a series of hand pollinations were made on the only available clonal material, situated on the Government Cacao Cultivation at River Estate.

At that Estate there are 28 clones of ten budded trees situated in seven rows of 4 clones. The scions only are clones while the stocks are healthy seedlings from hardy trees.

Methods.

Eight clones planted in two rows of 40 trees were selected for study. The flowers used for pollination were freshly opened each morning. It was found that although the flower opens at daybreak the anthers do not dehisce until 6.30 a.m. At noon an examination of the anthers showed that very little pollen remained in them. The pollen was often lying loose on the petal or had been removed by the numerous insects which visit the flowers. The period during which pollinations may be made each day was thus restricted to about five hours, in which time it was not possible to pollinate more than 150-200 flowers.

Some attempt was made to distribute the pollinations so that on each tree of a clone five flowers should be selfed and five cross-pollinated but as some of the trees were not flowering or otherwise unsuitable the actual numbers varied and were made up so that the total number of pollinations of each type should be approximately 50. The actual pollination was effected by brushing the stigma lightly with two or three open anthers until the pollen transferred was visible to the naked eye.

(1) Unpublished Dissertation in the I.C.T.A. Library.

(2) Fertilization and Embryogeny in Theobroma Cacao. *Ann. Bot.*, 41 (1927), 107-125.

No attempt was made to guard the flowers against natural pollinating agents. The necessary manipulations would have reduced so seriously the number of flowers which could be handled daily, that the disadvantage was judged greater than the advantage. From existing knowledge of cacao pollination, the chance of fruit setting by natural pollination is about 5 per cent. under favourable circumstances, and the chances of contamination of stigmas already well loaded with artificially applied pollen would undoubtedly be less. Thus it is impossible for natural agents to obscure the effects of the hand pollinations, and it is better to work with a large number of unguarded flowers than with a small number of guarded.

Each flower treated was tagged with a piece of coloured wool tied around the pedicel. Counts were made three days after pollination, by which time all the unpollinated flowers opened on the same morning had fallen, and again six days after pollination, when the pistils had swollen to a length of about 4 mms. and could be taken definitely as "set".

The whole experiment was carried out three times, once in August when setting was fairly general, again in September and a third time in December. The general averages show that conditions were markedly different on the three occasions and the results common to all these experiments cannot therefore be fortuitous.

Table 7.

PERCENTAGE OF FLOWERS REMAINING SIX DAYS AFTER POLLINATION.

Pollination.	Aug.	Sept.	Dec.	Mean.
1×1 ..	71	64	43	
2×2 ..	11	17	6	
3×3 ..	77	58	55	
4×4 ..	64	27	86	
5×5 ..	..	2	0	
6×6 ..	..	4	19	
7×7 ..	50	39	25	
8×8 ..	69	9	29	
Mean of "selfs"	57	27	33	39
1×5 ..	93	77	56	
2×6 ..	100	59	66	
3×7 ..	85	70	62	
4×8 ..	56	36	86	
5×1 ..	..	62	70	
6×2 ..	..	0	24	
7×3 ..	..	23	60	
8×4 ..	..	70	48	
Mean of crosses	84	50	59	64

The outstanding feature of the results is the superiority of "foreign" to "self" pollen which is shown in 17 cases out of 20 possible comparisons on the sixth day.

The three exceptions are, clone 4, which did better with self pollen than with that of clone 8 on one occasion out of three, and on the total gave almost exactly the same result with either; clone 6, which gave consistently poor results either way; and clone 7, which behaved quite differently on the two occasions when it was crossed with clone 3.

In the case of clone 6, it is interesting to note the excellent effect of its pollen on clone 2 as contrasted with the poor set of either 6 or 2 when selfed, and equally interesting to note that the effect is not reciprocal, 6×2 being the poorest of the crosses.

Clone 5 is also a consistently poor setter with its own pollen, but sets well with pollen of clone 1, and in this case the effect is reciprocal.

Clones 1, 3 and 4 are consistently good setters with their own pollen and the advantages of crossing are less marked on them, especially in the case of 4. In the cases of 1 and 3, however, there does seem to be a definite though slight advantage.

These observations touch only the fringe of the subject of incompatibility in cacao but by demonstrating that it exists they open up wide fields for further research and for economic application—particularly in relation to clonal propagation.

To keep the relationship between setting and final yield in proportion it may be mentioned that at the time when the third experiment was carried out, less than 20 pods survived from about 1,400 pollinations made during the previous visits. Incidentally 15 of these were cross fertilised. The whole of this loss can scarcely be attributed to incompatibility and the next step must be to follow the history of each set fruit until it wilts or matures, which will be possible when clonal material is closer to hand. The loss prevented any counts or comparisons of the number of beans in ripe selfed and crossed pods but such will have to be made in the future. It has been found possible to make counts at an earlier stage, also, although the exact significance of the result remains to be established.

If an ovary which has been pollinated is examined about 6 days after pollination it will generally be noticed that some of the ovules have hardly grown at all, in fact some appear smaller than unpollinated ovules. The remainder have very obviously grown. If the ovaries are pickled in 50 per cent. alcohol for 24 hours before dissection, the small ovules appear brown and shrivelled while the large ones are white and turgid. There can be no mistaking the two kinds. The proportion of ovules which fail at this time varies considerably, and may reach 50 per cent. or even higher. The number which survive presumably bears a close relation to the

number of beans in the mature pod. If the proportion which failed was constant, we might attribute all the failure to lethal factors in the genetic constitution of the parent tree. With the proportion of failures varying widely, however, it is fairly clear that pollination is at fault, so that the ovules which fail may do so either because they have not been fertilized or because the union is such that the resulting zygote dies. The problem of separating the two effects is not a simple one, because in hand pollinations if only one-fourth of the pollen placed on the stigma was compatible there should still be sufficient grains for complete pollination of all the ovules.

Counts of the large and turgid ovules six days after pollination were made for random samples of five pistils from each of 14 sets of pollinations after the third experiment. At the same time the lengths of the pistils were measured. Only 14 sets could be counted since 5×5 gave no yield and 2×2 gave only 3 sets. In Table 8 the mean of 3 pistils from 2×2 is given and to complete the table the mean length of 5×5 is given as that of the unpollinated pistils.

Table 8.

Clone.	Mean length of ovary. *cms.*	Mean No. of good ovules.	Mean No. of ovules which failed.
Selfing.			
1×1	0.37	28.6	11.8
2×2	0.25	34.7	5.3
3×3	0.45	34.2	6.0
4×4	0.45	36.2	2.2
5×5	0.20	..	..
6×6	0.45	29.8	10.2
7×7	0.43	38.8	4.0
8×8	0.37	31.8	8.6
Mean	0.37	34.4 (−)	6.9 (+)
Crossing.			
1×5	0.37	31.4	9.8
5×1	0.45	44.0	2.8
2×6	0.43	35.6	4.0
6×2	0.41	28.8	12.4
3×7	0.37	34.0	4.6
7×3	0.42	35.0	10.2
4×8	0.44	36.4	2.8
8×4	0.49	34.6	5.8
Mean	0.42	35.0	6.6

If a large mean length of the pistil represents a good "get-away" then the average "get-away" on crossing is better than on selfing, but not significantly so. There is only one case (clone 3) where "get-away" on selfing is much better than on crossing.

On our theory of flower abscission we should expect the fertilisation which causes the greater initial rate of growth of the pistils to be the most successful one. The figures for crossing do not bring this out but those for selfing show a positive correlation between length of pistil at 6 days and the percentage of successful pollinations.

$$\left(r = .6957,\ n = 6,\ \begin{cases} p = .1, & r = .6215 \\ p = .05, & r = .7067 \end{cases} \right)$$

This correlation would occur by chance in less than 6 trials out of a hundred.

Neither in selfing nor crossing is there any correlation between the proportion of ovules which fail and the number of successful pollinations. This may be expected on the grounds that the number of ovules which fail depends on the number of pollen tubes which reach the ovules and effect fertilisation, whereas the number of successful pollinations depends rather on the vigour with which pollination can stimulate the mechanism which inhibits flower abscission.

Summary.

1. Comparison of the number of ovules in wilting and sound cherelles shows no evidence in favour of the theory that wilting may be due to incomplete pollination.

2. Eight clones at River Estate were tested for self incompatibility and three of them consistently gave very poor results on selfing judged on the number of successful pollinations surviving 6 days.

3. There was only one case where consistent poor results were obtained from crossing. This occurred when two of the practically self sterile clones were crossed together but the reciprocal cross was compatible.

4. There are indications of a correlation between the initial rate of growth of the pistil and the number of successful pollinations.

B. CHEMICAL AND ECOLOGICAL SECTION.

PART I.—AN ENVIRONMENTAL STUDY OF THE CACAO TREE.

By J. A. McDonald, A.I.C.T.A.

I.—Introduction.

For this ecological investigation, two plots were selected for comparison :—

(A) Torrecilla (Good Plot).

(I) This is a typical good cacao area where natural conditions are such that the cacao tree thrives and bears well.

The area is situated near Arima, at Torrecilla Estate, the property of Dr. T. G. Mason. It lies in a sheltered position close to the Arima River, and at an elevation of about 25 feet above the river water level. No cultivation beyond that needed for ordinary routine sanitation is ever practised on the field in which the plot occurs. The trees are lightly pruned once a year, and the weeds are cutlassed twice a year. There are no drains; the natural drainage down to the river is adequately good. For shade, mountain (*Anauca*) Immortel trees, planted irregularly, are utilised. The cacao trees are 80 to 100 years old.

The field containing the plot has the reputation of always having been the best bearing field of the estate. Unfortunately, no past records are available, but from 1st January to 30th June, 1931, an average of 69 pods per tree were picked. The area is typical of the lower vegas of the Northern Range of Trinidad.

(B) Las Hermanas (Bad Plot).

(II) A typical bad area, where cacao trees have made but fair growth, and have given very poor yields for the past few years, was selected for contrast with the last.

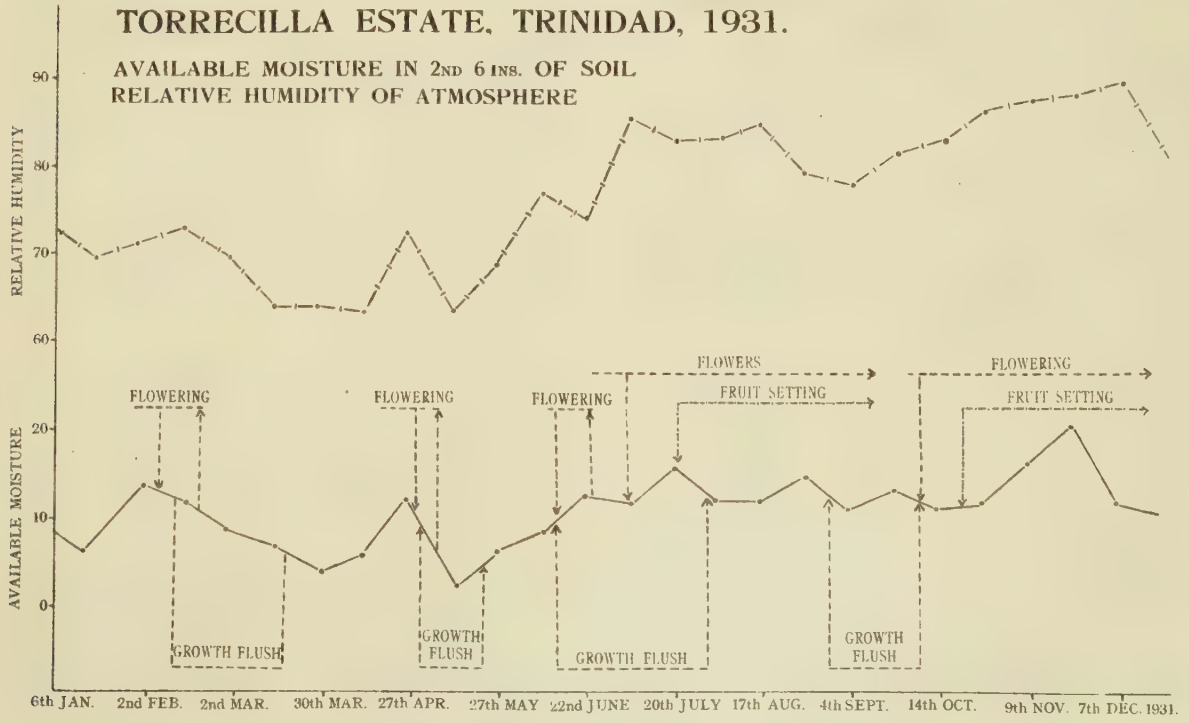
The bad plot is situated near San Rafael, at Las Hermanas Estate, the property of Messrs. Gordon, Grant & Co., Ltd. It lies on flat ground, about 250 yards from the Caroni River. The trees are lightly pruned once a year, and the weeds are cutlassed twice a year.

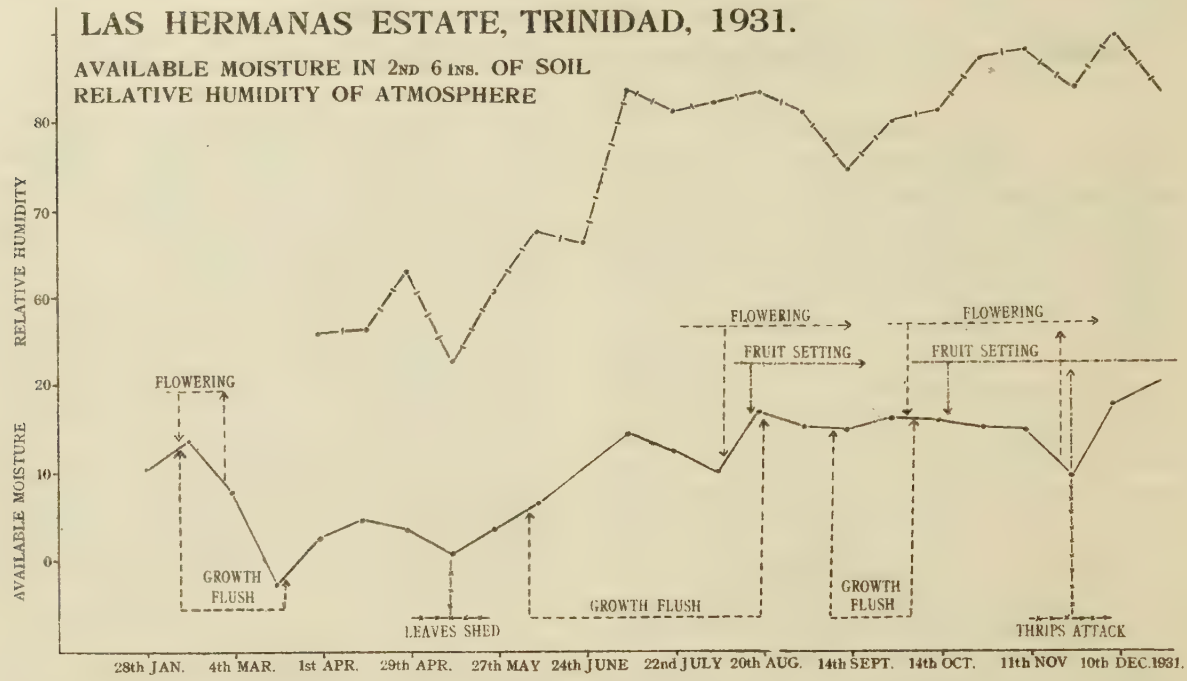
There is a net-work of 12-inch drains, 24 feet apart throughout the plot. For shade, there are water or plain Immortel trees (*Bocare*) planted 24 feet apart. A large amount of moss covers the trunks of the cacao trees, and many epiphytes are growing on the shade trees.

No past records of yields are available, but from 1st January to 1st June, 1931, an average of 11 pods per tree were picked. The plot is situated on alluvium of the Caroni River, and its soil is similar to that of the cacao vegas of the Caroni Plain.

It was our intention in establishing these two plots, to obtain as much information as possible concerning the environment of the cacao tree, and the responses which the tree makes to different types of environment and to changes in its environment.

For the first year, it was not intended to study any specific problem, but rather to establish routine measurements of environmental conditions which could be continued, if necessary, over a longer period of time without requiring too much attention and labour. Such information collected over an entire wet and dry season, together with field notes on the behaviour of the cacao tree,





would be extremely valuable in indicating methods of attacking more specific ecological problems which may later require investigation.

A start has already been made on one such derived problem; namely a detailed study of the effect of nitrogen fluctuations on the behaviour of the cacao tree, but sufficient data has not yet been collected to warrant special inclusion in this report.

The following routine measurements of environmental conditions at each of the plots were made.

(2) Environmental Factors, and Methods of Observation.

(*a*) *Rainfall.*—Recorded by means of a recording rain gauge (tilting bucket type).

(*b*) *Shade temperature.*—By means of a thermograph operating on the bimetallic principle, enclosed in a Stephenson screen at a height of 5 feet above the ground level.

(*c*) *Evaporating power of the air.*—By means of Livingston standardised porous atmometer-bulbs at three levels, *i.e.* (1) top of cacao trees, (2) middle range of the foliage, (3) underneath the trees (4 feet above ground level).

(*d*) *Radiation.*—By means of Livingston paired black and white radio-atmometers, at three levels as above (*c*).

(*e*) *Relative humidity of the atmosphere.*—By means of a hair hygrometer, enclosed in a Stephenson screen at a height of 5 feet from the ground.

(*f*) *Soil temperature.*—By means of a Negretti and Zambra distance recording thermometer. The bulb was placed horizontally at 3 inches depth below the surface.

(*g*) *Soil moisture.*—Fortnightly auger samples were collected from three different levels; *i.e.*, first 6 inches, second 6 inches, second foot.

(*h*) *Level of water table.*—Five perforated iron pipes were sunk to a depth of 3 feet 6 inches in the ground in each plot. Each pipe was covered with a tin lid to keep out rain. Weekly measurements of the water-table level were taken with a measuring stick.

(*i*) *Field notes.*—On each weekly visit to the experimental plots, notes were made with regard to the condition of the trees, and to flowering, setting of fruit, growth flushes, &c.

These various measurements have been carried out on the Torrecilla (good) plot since January, 1931, and on the Las Hermanas (bad) plot since March, 1931. Soil temperature measurements were only started on the Las Hermanas (bad) plot in November, 1931. Measurements of water table level were started on both plots on 13th April, 1931.

It will be seen that, where possible, automatic recording instruments have been used. By employing such apparatus, it has not been necessary to visit the experimental plots more than once a week.

Before setting up, all instruments were carefully standardised, and were subsequently checked from time to time as follows:—

(*a*) *Rain gauges.*—The recording gauges were checked by taking daily measurements with a standard 8 inch gauge over a period of a week or ten days.

(*b*) *Thermographs* were checked every week against standard maximum and minimum thermometers placed in the same screen.

(*c*) *Humidity recorders* were calibrated by saturating the hair and setting the reading at 95 per cent.

(*d*) *Livingston atmometer bulbs* were originally standardised in the Livingston laboratories, Baltimore, U.S.A., and a factor recorded on them before being delivered. The atmometers were checked by placing them at three different levels in sets of six, three black and three white. Thus, if any bulb became clogged or failed to function properly, it was immediately detected and replaced.

(*e*) *Recording soil thermometer* was checked against spot readings with a standard soil thermometer.

Summarized meteorological and environmental soil data are presented in Table II, and certain factors and observations are also plotted on graphs which accompany this report.

(3) Soil Examination.

In addition to the above regular observations, the soils of the two plots were sampled by the profile method to a depth of 5 feet for full examination in the laboratory.

The analytical results for the soil profiles are given in Table I.

(4) Discussion of Results.

(I) Soil Data—(Table I).

(*a*) *Texture and Physical Condition.*—The soil of the Torrecilla (good) plot is an alluvial sandy-loam, containing some gravel, through which water percolates readily. It is underlain by large stones and boulders at a depth of 3 feet 6 inches to 4 feet, which provide excellent natural drainage, and ensure against water-logging, even during periods of heavy rainfall.

The soil of the Las Hermanas (bad) plot is a compact, impervious, alluvial silt. The profile pit showed a blue-grey mottled layer (at a depth of 9 inches) which is generally associated with bad aeration and reducing conditions. Measurements in the drainage tubes throughout the year showed that, during the wet season, the average depth of the water-table below the surface is here only 15 inches.

(*b*) *Reaction.*—The soil is slightly acidic in the top layers of the Torrecilla (good) plot, and markedly to highly acidic in the lower layers; "exchange" acidity is low throughout.

Table I.

Soil profile data for good and bad cacao plots.

Profiles.	Lower Depth. (ins.)	Index of Texture. (I.T.)	Reaction. Norm. pH.	Reaction. Exch. pH.	O.M. Content. %	N. Content. %	C/N Ratio.	Easily Avail. Nutr. (Conduc.)	Rate of Soln. mhos × 10-6	Avail. Phosphate. p.p.m.	Avail. Potash p.p.m.
Bad Site. Las Hermanas Estate, San Rafael.											
LHX. 1 Humic, leafy ..	1½	52	6.8	6.4	5.85	0.40	8.5	209	506	41	72
LHX. 2 Uniform, pale ..	3	48	6.6	6.0	2.81	0.28	5.9	112	185	24	77
LHX. 3 do. ..	6	46	5.7	4.7	1.65	0.20	4.8	76	64	21	69
LHX. 4 Faint mottling ..	9	43	5.0	4.0	0.80	0.13	3.5	38	7	15	79
LHX. 5 Mottled tawny ..	12	43	4.8	3.9	0.68	0.12	3.3	37	6	11	70
LHX. 6 Coarse mottling..	18	42	4.9	4.1	0.57	0.11	3.1	29	4	11	65
LHX. 7 Coarse dull ..	24	42	4.8	3.7	0.52	0.10	2.9	32	8	14	50
LHX. 8 do. ..	32	38	5.0	3.8	0.50	0.10	2.8	38	11	15	49
LHX. 9 Coarse, streaked	41	37	5.1	3.9	0.51	0.10	3.0	84	13	17	48
LHX. 10 Grey ..	50	36	5.2	3.9	0.40	0.09	2.4	154	24	17	61
Good Site. Torrecilla Estate, Arima.											
TX. 1 Humic	1½	8	7.0	6.7	4.85	0.34	8.4	192	147	131	94
TX. 2 do.	3	8	6.4	5.8	3.71	0.25	8.7	71	41	135	118
TX. 3 Paler, humic ..	6	14	6.2	5.6	2.14	0.15	8.4	45	19	149	112
TX. 4 Paler, gravelly ..	9	12	6.1	5.4	1.10	0.10	6.6	41	7	?	?
TX. 5 do. ..	12	11	5.7	4.8	0.78	0.07	6.3	29	7	122	92
TX. 6 Paler, speckled ..	15	13	5.4	4.6	0.56	0.07	4.7	34	4	104	102
TX. 7 Streaky, speckled..	18	14	5.1	4.4	0.38	0.06	3.7	52	4	112	87
TX. 8 Uniform	24	16	4.9	4.3	0.27	0.07	2.2	56	2	122	82
TX. 9 Faintly patchy ..	30	16	4.9	4.3	0.18	0.05	2.0	52	1	118	59
TX. 10 do. ..	36	15	4.9	4.2	—	0.05	—	42	3	?	?
TX. 11 Stoney layer ..	48	16	4.9	4.2	—	0.05	—	39	1	105	39

In the Las Hermanas (bad) plot soil, the reaction of the top layers is slightly acidic, and of the lower layers, highly acidic. "Exchange" acidity is high throughout the profile, and particularly high from two feet downward. (A slightly acidic reaction in the top soil is believed not to be particularly harmful, however, since it does not hinder the growth and development of beneficial soil micro-organisms.)

(*c*) *Organic matter content.*—This is high, and penetration is good down to one foot, for the soil of each plot.

(*d*) *Total Nitrogen* is high in both soil-profiles, but is considerably higher in the Las Hermanas (bad) soil profile.

(*e*) *Carbon/Nitrogen ratio* is 8.5 for the first 6-inch layer of the Torrecilla (good) plot soil, and 6.0 for the first 6-inch layer of the Las Hermanas (bad) plot soil. This difference is in accordance with the findings of Hardy and Griffith, who have shown that good-yielding cacao soils possess a wider C/N ratio than poor-yielding soils.

(*f*) *Nutrient status*, as shown by the results of electrical conductivity measurements, is fairly high for the first 6 inches of the Torrecilla (good) soil, but very low for the deeper layers.

In the Las Hermanas (bad) soil, easily available nutrients and rate of solution of potential nutrients are both very high for the top 6-inch layer. The middle layers show very low values, which tend to rise again, however, from 4 feet downwards. These high values for the top 6-inch layer may be due to the accumulation of excessive quantities of nitrate in the soil of the bad plot.

(*g*) *Available phosphate* (By Truog's method). Truog states that values approximating to 57 parts per million for light soils, and 85 parts per million for heavy soils, are critical values. Follett-Smith, in British Guiana, obtained a critical value of 30 parts per million for sugar-cane soils.

In the Torrecilla (good) soil profile, the top 6-inch layer of soil contains over 130 parts per million, and all layers contain over 100 parts per million. These results suggest that available phosphate is present in adequate quantities throughout this profile.

In the Las Hermanas (bad) plot soil profile, the average value for the top 6-inch layer is only 29 parts per million, and only 15 parts per million for the lower layers. These values are below the accepted critical standards, and indicate a great deficiency of phosphate.

(*h*) *Available potash* (soluble in 1 per cent. citric acid). Dyer gives 100 parts per million as a critical value for this factor. Maurice Bird, in British Guiana, obtained a critical value of 50 parts per million for light soils, and 100 parts per million for heavy soils growing sugar-cane.

The top 6-inch layer of the Torrecilla (good) soil profile contains 108 parts per million, and the average value for the lower layers is about 75 parts per million. These values are just above the accepted critical point, and indicate that available potash is present in quantities sufficient for good plant growth (that is, assuming that the nutrient requirements of the cacao tree is approximately the same as that of the sugar-cane plant).

The top 6-inch layer of the Las Hermanas (bad) soil profile contains 72 parts per million, and the average value for the lower layers is 57 parts per million. Since the soil possesses a clayey-texture, these values may be considered to be below the critical value for good plant growth.

(II) Environmental Data.—(Table II).

In the presentation and discussion which follows, the Torrecilla plot will throughout be designated the "good" plot, and the Las Hermanas plot will be designated the "bad" plot.

(*a*) *Rainfall.*—The rainfall from January until the end of October, 1931, was normal in distribution and amount. During the first five months of the year (dry season), only 6.32 inches of rain fell at the good plot. The driest period extended from the beginning of March to the end of May, when only 2.75 inches fell in three months. The rainy season began early in June, the wettest months being July, August, November and December. From the 25th November to the end of December, the duration and intensity of the rainfall on the bad plot was exceptionally high. During the same period at the good plot, the duration of the rainfall was very high, but the intensity was not so great as the rainfall of the bad plot. At the good plot, the total rainfall for the whole year (1931) was 74.42 inches, and at the bad plot, the rainfall from April to December was 91.91 inches.

(*b*) *Soil moisture.*—Since the soil of the bad plot is much heavier in texture than the soil of the good plot, the gross soil moisture figures cannot logically be compared. The wilting coefficient of the two soils at the different depths sampled, may be calculated, however, by applying the Briggs-Shantz formula:—

$$W \text{ (Wilting Coefficient)} = \frac{M \text{ (Maximum water-retaining capacity)} - 21}{2.9}$$

The wilting coefficients thus obtained are as follows:—

Torrecilla (good) plot.	Per cent.	*Las Hermanas (bad) plot.*	Per cent.
(Percentages on oven-dry soil basis.)			
First 6 inches ..	15.9	First 6 inches ..	27.5
Second 6 inches ..	12.5	Second 6 inches	26.0
Second foot ..	11.0	Second foot ..	24.3

When these figures are subtracted from gross soil moisture content, a measure of the available moisture at the time of sampling is obtained. The figures in Table II represent available soil moisture contents thus calculated.

A systematic study of soil moisture conditions throughout the year would be expected to yield most interesting results during the two periods which may be considered critical from the point of view of the plant, namely (1) at the height of

Table II.

Summarized data for environmental factors (atmospheric and soil) for "good" and "bad" cacao plots.

Year 1931.		Rainfall.	Available Soil Moisture. (Per cent. Oven-dry soil)			Relative Humidity of Atmosphere.	Evaporating Power of Air. (cc. per 24 hours.)			Radiation. (cc. per 24 hours.)			Temperatures.					
							Canopy Strata.			Canopy Strata.								
		Inches.	1st 6-in.	2nd 6-in.	2nd ft.	Average Day Humidity (Per cent.).	Top.	Mid.	Lower.	Top.	Mid.	Lower.	Max. Shade Temp.	Min. Shade Temp.	Range.	Max. Soil Temp.	Min. Soil Temp.	Range.
January	Good plot	1.52	8.5	9.1	9.3	70.8	10.5	6.2	8.5	8.2	2.6	1.5	83.3	68.6	14.7	74.9	71.9	3.0
	Bad plot	—	14.6	11.1	9.9	—	—	—	—	—	—	—	—	—	—	—	—	—
February	Good plot	1.88	11.5	9.5	9.5	70.6	11.8	9.4	10.3	9.1	5.2	1.8	84.4	70.1	14.3	76.3	73.9	2.4
	Bad plot	—	13.5	11.5	9.5	—	—	—	—	—	—	—	—	—	—	—	—	—
March	Good plot	0.17	6.4	5.2	5.7	63.8	17.5	16.2	16.3	12.3	7.0	2.9	88.1	72.5	15.6	77.0	74.2	2.8
	Bad plot	—	3.8	0.6	2.1	56.3	21.6	16.0	17.7	10.2	5.4	5.6	88.1	66.9	21.2	—	—	—
April	Good plot	2.36	8.3	8.2	8.5	67.6	17.5	14.7	15.7	10.6	6.9	2.8	86.3	73.9	12.4	77.3	74.4	2.9
	Bad plot	2.04	6.0	4.3	4.6	60.3	20.3	16.4	17.2	7.4	5.8	5.4	88.0	69.6	18.4	—	—	—
May	Good plot	0.39	1.7	3.3	4.6	66.5	17.3	17.1	14.3	9.1	7.4	3.4	86.4	74.0	12.4	78.7	76.3	2.4
	Bad plot	0.64	2.2	2.4	1.4	57.1	23.4	19.4	21.8	7.8	7.0	6.6	89.2	69.3	19.9	—	—	—
Dry Season	Good plot	6.32	7.3	7.1	7.5	67.9	14.9	12.7	12.9	9.9	5.8	2.5	85.7	71.8	13.9	76.8	74.1	2.7
(Means)	Bad plot	2.68	8.0	6.0	5.5	—	—	—	—	—	—	—	—	—	—	—	—	—
June	Good plot	7.41	12.2	9.8	7.7	80.0	11.6	10.6	8.9	7.8	6.6	2.0	82.4	72.9	9.5	78.6	75.9	2.7
	Bad plot	7.75	11.9	11.0	10.1	72.9	15.4	11.2	13.2	6.1	4.9	4.6	84.4	70.4	14.0	—	—	—
July	Good plot	13.54	18.8	12.7	9.7	82.3	7.0	6.2	4.7	6.4	5.5	1.3	81.6	72.9	8.7	77.4	75.4	2.0
	Bad plot	14.06	15.3	11.9	13.1	82.2	9.4	5.6	6.2	5.6	4.2	3.9	82.1	69.7	12.4	—	—	—
August	Good plot	9.24	18.5	13.3	12.7	81.6	9.0	6.7	6.0	7.4	5.7	1.7	81.7	72.7	9.0	77.4	75.4	2.0
	Bad plot	14.83	24.1	16.8	15.1	82.6	9.5	5.9	5.8	5.6	4.4	3.3	82.8	71.0	11.8	—	—	—
September	Good plot	4.44	16.4	11.7	10.5	79.4	14.6	7.6	7.4	8.4	5.1	2.0	83.7	73.1	10.6	78.0	75.2	2.8
	Bad plot	5.82	19.4	16.0	13.9	77.7	12.3	9.4	7.1	6.8	4.6	3.2	85.6	70.1	15.5	—	—	—
October	Good plot	8.54	11.5	10.9	11.1	84.8	10.8	4.6	4.6	6.6	3.6	1.5	81.7	72.3	9.4	77.4	75.0	2.4
	Bad plot	9.11	18.7	16.4	15.8	84.5	8.5	4.2	4.3	5.4	3.0	2.6	83.6	70.6	13.0	—	—	—
November	Good plot	12.54	24.1	16.0	13.4	87.3	9.4	4.1	3.7	6.4	2.3	1.3	80.2	72.9	7.3	77.2	75.2	2.0
	Bad plot	15.63	20.2	14.5	13.2	86.5	8.7	3.8	4.5	4.7	3.5	3.8	81.2	71.6	9.6	—	—	—
December	Good plot	12.39	17.9	11.9	10.2	85.4	10.9	3.9	2.2	6.5	2.7	0.6	79.4	70.9	8.5	74.7	72.9	1.8
	Bad plot	22.03	32.0	19.3	17.5	85.0	5.6	3.2	2.5	4.8	3.2	1.8	79.4	69.4	10.0	78.1	74.8	—
Wet Season	Good plot	68.10	17.1	12.3	10.8	83.0	10.5	6.2	5.4	7.1	4.5	1.5	81.5	72.5	9.0	77.2	75.0	2.2
(Means)	Bad plot	89.23	20.2	15.1	14.1	81.6	9.9	6.2	6.2	5.6	3.9	3.3	82.7	70.4	12.3	—	—	—
Whole year	Good plot	74.42	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
(Means)	Bad plot	91.91	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

the dry season when the soil becomes desiccated to such an extent that the plant may have difficulty in obtaining sufficient water, and (2) at the height of the wet season, when the soil is apt to become water-logged.

As was to be expected from the rainfall figures, the soil contained the smallest amount of available moisture during May, and the greatest amount during July, August, November and December. During these two periods, the moisture contents of the soil of the two plots show interesting differences, particularly in the sub-soil layers between 1 and 2 feet depth.

The data for available moisture contents in the two plots in the second foot of soil shows that, in the bad plot, moisture conditions approached much nearer to the wilting point during the dry season than in the good plot. During the rainy season, however, available moisture in the subsoil was considerably higher in the bad plot than in the good.

It may be mentioned here that, at the beginning of May, the cacao trees within the bad plot began to shed leaves from the ends of their branches, and, by the end of May, the plot presented a very bare and ragged appearance. With the first rains in June, new growths, however, were established.

At no time during the year did the good plot show signs of wilting. On 12th November, and throughout the latter half of November, the bad plot was noticed to be suffering from an attack of *thrips*. The soil moisture values recorded in Table I show that available sub-soil moisture was very low in the bad plot during the critically dry months (*i.e.*, March, 2.1 per cent., and May, 1.4 per cent., compared with March, 5.7 per cent., and May, 4.6 per cent. for the good plot). For the second 6 inches also there was less available moisture during the dry months on the bad plot. Nevertheless, during the driest month (May), the available moisture in the *top soil* was higher in the bad plot than in the good plot.

These results indicate that during periods of drought when the surface layers of the soil are excessively dry, the ability of the cacao tree to tide over the critical period, depends on the amount of moisture which is supplied by upward movement from lower levels.

(*Note.*—Experiments on the relation of soil moisture to plant growth recently carried out in California have shown that losses by evaporation directly from the soil surface are relatively slight as compared with losses by leaf transpiration. These conclusions indicate that, with regards to cacao cultivation, mulching at the end of the wet season might be more beneficial in conserving soil moisture than supplying additional ground-shade, such as Bananas and Balisier.)

(*c*) *Level of the water-table.*—Weekly measurements in the drainage tubes were started on 13th April, 1931. Within the good plot, from 13th April to 14th June, 1931, water was found only on 20th April, when the average depth of the water-table below the surface was 36 inches. On all other occasions during the dry season, the water-table here was well below the 3 feet 6-inch level. During the wet season, water was found above the 3 feet 6-inch level on every occasion except 24th August, 28th September, and 5th October. The average level of the water-table during the wet season was 2 feet 11 inches below the surface.

On the other hand, at the bad plot, from 13th April to 21st June, water was found above 3 feet 6-inch level every week. The average depth of the water-table during the dry season was 3 feet 3½ inches. During the wet season, the average depth of the water-table was only 1 foot 3 inches in the bad plot.

(*d*) *Evaporating power of the air.*—Measurements of the evaporating power of the air with Livingston atmometers show that, at the middle level, the evaporation throughout the year at both plots was nearly the same. At the tops of the cacao trees, and at the ground level, however, the evaporation during the dry season at the bad plot was markedly higher than the evaporation at the good plot.

When the rains began in June, the evaporation on both plots decreased, and the difference in evaporation between the two plots diminished, until, from August to the end of the year, the evaporation at the bad plot fell below that at the good plot. It will be noticed that, at the bad plot, by far the highest evaporation took place during May, especially at ground level. During this period, the cacao trees were shedding their leaves, thus subjecting the ground to much greater exposure. At the good plot, no marked leaf-shedding took place, and the period of highest evaporation extended fairly uniformly from March to May.

Measurements of the evaporating power of the air have shown :—

(1) There is a higher dry season evaporation at the bad plot than at the good plot, particularly at the ground and top level.

(2) After the commencement of the rains, the difference in evaporation between the two plots decreased, so that, from August onwards, the bad plot showed a tendency to a lower evaporation rate, particularly at the top level.

(3) The driest months of the year (highest evaporating power of the air) were March, April and May. The wettest months (lowest evaporating power of the air) were July, August, November and December. At the good plot, the evaporating power of the air was uniformly high during the dry period, but at the bad plot, the evaporating power of the air was far higher during May than during any other month. At ground and middle levels, the lowest evaporation for the year on both plots was recorded during December.

(*e*) *Light intensity.*—The figures in Table I represent the amount of evaporation (cc. per 24 hours) due to absorbed radiation only.

At the good plot (lower and middle levels), a period of uniformly high light intensity extended from March to May, 1931. This was also the

period of highest light intensity at the bad plot, but here, a distinct peak occurred during May, when the cacao trees had shed most of their leaves.

At the top level, above the cacao trees, radiation was at its highest intensity at the good plot during March, and afterwards showed a steady decline month by month until July, when it rose again to another peak in September. There are no records for January and February for the lower levels at the bad plot, but the available results for the top level show a similar trend.

Comparing the two plots, it will be seen that, at the top and middle levels, the intensity of radiation at the good plot is appreciably the higher. At ground level, however the radiation at the bad plot is much the greater. These results may be explained as follows:—At Torrecilla (good plot) there are fewer shade trees, and the type of Immortel tree grown as shade is the *Anauca*. or mountain variety, which is very tall, and holds its foliage at a considerable height (50 to 60 feet) above the tops of the cacao trees, so that very little light is actually stopped by the shade trees.

On the Las Hermanas (bad) plot, however, the Immortel shade trees are of the *Bocare* or plains variety, and are spaced closely together. The shade trees are small, and their foliage is near the tops of the cacao trees, thus effectively shading them, both laterally and vertically. On the other hand, at the good plot, the ground surface is much more closely shaded than at the bad plot.

Measurements of light intensity have shown:—

(1) That the intensity of radiation at the bad plot is lower at the levels of the tops of the cacao trees, and in the middle range of the foliage, than at the good plot.

(2) The intensity of radiation at the bad plot is much higher at the ground-level than at the good plot.

(*f*) *Relative humidity*.—In comparing the figures given for evaporating power of the air with those for relative humidity, some interesting results emerge. The relative humidity recorder was placed on the same level as the lower box of atmometers, so that the two sets of data should be comparable. An inspection of these data indeed indicates that results given by the two methods are very closely related. Both show considerably dryer conditions on the bad plot during the dry season. After the commencement of the rains, both sets of figures show the same general increase of humidity, with a decrease in the difference between the two plots, until, from July onwards, air moisture conditions at the two plots at this low level became nearly the same. The most striking inference that can be drawn from the two sets of records is that the humidity instrument does not emphasize the extremely exposed and desiccated condition of the bad plot during May, whereas the atmometers bring out this feature very clearly. The Livingston atmometers possess the advantage that they record in addition to the evaporating power of the air, the total amount of radiant energy that falls on any one particular spot. Evidently, therefore, the Livingston atmometer equipment furnishes a very useful means of comparing environments both as regards evaporation and insolation, and is superior in these respects to humidity recorders.

(*g*) *Temperature*.—The values for the mean maximum and minimum temperatures at the two plots throughout the year, demonstrate that, at the good plot, highest day temperatures occurred during March, and lowest day temperatures during November and December. Night temperatures rose steadily from January to their highest point in May. With the commencement of the rains in June, night temperatures fell slightly and then remained nearly constant until November. The greatest range of temperature (24 hours monthly mean) was 15.6° F. during March, and the smallest range, 7.3° F. in November.

At the bad plot, the highest day temperatures occurred during May, and the lowest day temperatures during November and December. Night temperatures rose steadily throughout the year to a maximum in November. Unfortunately there are no records for January and February, the two months during which the coolest nights for the year generally occur. The greatest ranges of temperature were 21.2° F. during March, and 19.9° F. during May. The smallest range of temperature was 9.6° F. during November.

Comparing the two plots, it will be seen that there was a greater daily range of temperature at the bad plot than at the good plot, and the day temperatures there were higher, and the night temperatures lower. The hottest month of the year (1931) at the good plot was March; the hottest month of the year at the bad plot was May.

Soil temperatures at the good plot at a depth of 3 inches varied only slightly, both during the day and throughout the year. Soil temperatures were highest during May and June and lowest in January and December. (No soil thermometer is installed at the bad plot, so that comparable data are lacking.)

(5) Response of the Cacao Tree to Environmental Conditions.

(*a*) *Growth flushes*.—At the good plot, there were four big growth-flushes throughout the year (1931), as follows:—

(1) 8th February to 20th March; (2) 1st May to 25th May; (3) 15th June to 1st August; (4) 10th September to 10th October.

The data include available soil moisture contents of the second 6-inch layer of soil determined fortnightly throughout the year, and also the fortnightly mean relative humidity at both plots. The beginning and ending of the growth-flushes, and the times of flowering and setting of fruit, are marked on the accompanying graphs.

At the bad plot, there were only three main growth-flushes throughout the year, namely, (1) 8th February to 20th March; (2) 8th June to 20th August; (3) 10th September to 10th October.

The main differences between the two plots are that, at the bad plot, no growth-flush took place during May, and the big growth-flush in June began about a week earlier and ended about 3 weeks later than at the good plot.

At both plots, growth-flushes were always accompanied by some change of leaf, that is, during the time when new leaves were being put out, old leaves were being shed. The most marked leaf change occurred on both plots during the February flush, but some leaf shedding also took place during the flush in June to July. At the good plot, marked leaf-shedding also took place during the flush in May, but at the bad plot, the trees shed their leaves in May without putting out any new growth (wilting). Although no signs of wilting were observed on the good plot, the wet season leaf-canopy was noticeably heavier than during the dry season.

(*b*) *Flowering and setting of fruit.*—At the good plot, there was some flowering at the end of January and during the first week in February, but many of the flowers formed at this time were shed during the subsequent dry weather. Following the heavy shower of rain at the end of April, many flowers were put out during the first week in May, but again, all these flowers were shed during the subsequent dry spell in May. On 15th June, many flowers were once more observed on the trees, but about a fortnight later, when the growth-flush was at its height, these flowers also were shed. On 7th July, another burst of flowering took place, and towards the end of July the first young cherelles appeared on the trees. Flowering and setting continued until the middle of September, and then again from the middle of October till the beginning of December. No flowers were observed on the trees during the latter part of December, and many of the young cherelles turned black, owing perhaps to the high humidity.

At the bad plot, flowering took place during the last week in January and the beginning of February, but these flowers were subsequently shed. No more flowering was observed until the first week of August. Young cherelles were first noticed on the trees during the second week of August. Flowering and setting continued from this date until the middle of September, and then started again in the middle of October and continued until the first week of December. Some flowers and young fruits were shed during the second week of November, when the trees were seen to be suffering from an attack of thrips. No flowers were observed on the trees during the latter half of December, and many young fruits turned black.

From a consideration of the foregoing notes and data, interesting relationships are apparent between moisture conditions and the behaviour of the cacao tree with regard to growth-flushes, flowering, fruit setting and leaf shedding. Thus, following a rise in soil moisture, the trees were stimulated to put out new leaves and flowers. When moisture conditions were not maintained at a high level, however, all the flowers and a large part of the old foliage were shed during a flush of growth. Following the rise of soil moisture at the end of April, a flush of growth took place at the good plot. At the bad plot, although showers of rain fell during April, soil moisture was not appreciably affected, and no flush of growth occurred. The behaviour of the cacao trees at the two plots at the beginning of the rainy season exhibited marked differences. At the good plot, the first rise in soil moisture stimulated the trees to put out new leaves and flowers, but, although high soil moisture conditions were maintained, these flowers were shed when the growth-flush was at its height. The reason for this was probably that, at this time, the trees were unable to support both the flowers which had been put out, as well as the heavy flush of growth necessary to renew the depleted dry season leaf-canopy. About two weeks later, however, when the growth-flush was past its most vigorous stage, more flowers were put out, which subsequently developed into young fruits.

At the bad plot, towards the end of the dry season, many of the branches of the cacao trees were completely devoid of leaves. With the beginning of the rains in June, new vegetative growths appeared, but no flowers were formed. It would therefore appear that the entire vigour of the tree was taken up with renewing its foliage. At this plot, no flowers were developed until the first week of August, when moisture conditions had attained a high level, and vegetative growth had nearly ceased. During the "Indian Summer" (which occurred during September and the early part of October), a flush growth occurred at both plots. Soil moisture conditions did not alter appreciably at either plot, but atmospheric moisture conditions fell considerably below the normal wet season level. Atmospheric humidity was highest at both plots in November and December, and, during this period, many young fruits turned black on the trees. It is interesting to note that, at the time when the thrips attack occurred at the bad plot, available soil moisture showed a sharp decline, but atmospheric humidity still remained very high (81 per cent. relative humidity). Evidently a diminution of leaf moisture, such as would result from changes of this nature, favours attacks by thrips.

(6) Summary of General Conclusions.

Two experimental plots were selected at the beginning of 1931 in order to study the environmental factors affecting the growth of the cacao tree in Trinidad. A good-yielding site ("good" plot), and a poor-yielding site ("bad" plot) were chosen for comparison. A close examination of soil conditions, and continuous observations of fluctuating environmental factors

have been carried out over a period of one year. The methods adopted, and the results of observations and analyses are presented and discussed.

General conclusions based on the year's observations are briefly as follows:—

(I) Soil Data.

(1) There are obvious differences in texture and physical condition, which indicate the need for more effective drainage at the bad plot.

(2) The impervious nature of the soil, and the high exchange soil acidity of the bad plot, indicate that liming here might be beneficial.

(3) The Carbon/Nitrogen ratio of the first 6-inch layer of soil at the bad plot is very low (6.0). This is in accordance with a generalization that good-yielding cacao soils have a higher ratio than bad-yielding soils. (*Note.* A low C/N ratio usually implies an adequate production of soil nitrate, and suggests the need for heavy mulching with materials (such as rice straw, grasses, or any easily decomposable vegetable matter (except leguminous plants) that possesses a high C/N ratio.) Treatment of soils of low C/N ratio with nitrogenous manure would appear to be unwarranted, or even wasteful.)

(4) The values given for available soil phosphate are very widely different for the two plots. The good plot soil contains about eight times as much available phosphate as the bad plot soil, for which the values are below the critical point given by various workers using the same method.

Manuring the bad plot with mineral phosphates might yield interesting results.

(5) The values for available potassium do not show such a marked difference between the two plots as do the available phosphate figures; but the values for the good plot soil are the higher. (108 p.p.m. as against 75 p.p.m. for the top 6-inch layer of soil.)

Considering the critical potash values given by various workers for this method, the good plot soil may be considered to be just above, and the bad plot soil, just below the critical point.

(II) Environmental Data.

(1) *Soil moisture conditions.*

(*a*) Measurements of water-table levels throughout the year have shown that, after heavy rains, the level of the water-table at the good plot quickly falls to a level of 3 feet or more below the ground surface. During dry weather, the water-table lies at a depth greater than 3 feet 6 inches below the surface.

At the bad plot, on the other hand, the level of the water-table during the rainy season is consistently high (only 15 inches below the surface), and, even during the dryest months, water was found at a depth of 3 feet 3 inches below the surface.

(*b*) Regular fortnightly measurements of soil moisture at the good plot during the dry season have shown that, although the top 6 inches of soil become nearly depleted of available moisture during critically dry periods, the second 6 inch layer and second foot of soil still contain an appreciable quantity of available moisture. Soil moisture measurements at the bad plot during the dry season, have shown that the soil becomes depleted of available moisture to a greater depth than at the good plot. At the height of the dry season, the trees on the bad plot showed marked signs of wilting, whereas the trees on the good plot showed no ill effects from the dry weather.

During the wet season, available soil moisture was considerably higher in the bad plot than in the good, particularly in the second foot layer of soil. The high wet season water-table at the bad plot emphasizes the need for deeper drainage on this plot. Soil moisture conditions at the bad plot also indicate the need for minimising evaporation of moisture from the soil during the dry season, preferably by the application of surface mulches at the end of the wet season.

(2) *Atmospheric humidity.*

Measurements of atmospheric humidity by means of a relative humidity recorder, and evaporating power of the air by means of atmometers, have demonstrated that, at the level of the tops of the cacao trees, the atmospheric conditions at the bad plot favour a high rate of evaporation during the dry season and a lower rate of evaporation during the wet season than at a similar high level at the good plot. At ground level, there is a much higher evaporation, and a much lower humidity at the bad plot during the dry season than at the good plot. During the wet season, humidity and evaporation on both plots are nearly equal.

(3) *Light intensity.*

The results of measurements of the amount of radiation falling at different levels in the two plots assessed by means of Livingston paired black and white radio-atmometers indicate that at the good plot the tops of the cacao trees are more exposed to light, but the ground is more heavily shaded; than at the bad plot.

(4) *Temperature.*

Day temperatures at both plots have largely been influenced by atmospheric humidity. During the driest months, the highest day temperatures were recorded, and during the wettest months, the lowest day temperatures were recorded. The lowest night temperatures for the year were recorded during January and February. At the good plot, the highest night temperatures occurred during May; at the bad plot, night temperatures rose steadily throughout the year to a maximum in November. There is a greater daily range of temperature at the bad plot than at the good plot.

(5) *The response of the cacao tree to environmental conditions.*

(1) Records of crops picked from January to June, 1931, at the two plots show (*a*) the good plot yielded an average of 69 pods per tree, (*b*) the bad plot yielded an average of 11 pods per tree.

(2) The condition of the trees as regards flowering, growth-flushes, setting of fruit, &c., has been noted on each visit to the plots, and very definite relationships between moisture conditions and the behaviour of the cacao tree are indicated.

The soil and atmospheric moisture values showed distinctive fluctuations, namely, (*a*) when growth-flushes occurred, (*b*) when flowering occurred, (*c*) when setting of fruit took place, (*d*) when flowers were shed, (*e*) when young fruit were shed or turned black on the trees, (*f*) when the trees wilted during the dry season, and (*g*) when an attack of thrips occurred during the wet season.

* * *

PART II.—A SOIL SURVEY OF THE GRAN COUVA DISTRICT, CENTRAL RANGE, TRINIDAD.

By J. A. McDonald, A.I.C.T.A.

(1) Introductory.

The area that has been surveyed consists of approximately 28 square miles of that portion of the Central Range that surrounds Gran Couva Village.

We have endeavoured to differentiate and describe the various soil types which occur in this district, with a view to obtaining some information about those soil factors that have important bearing on the productivity of cacao soils.

(2) Geology of the District.

The geological formations from which the cacao soils of the Gran Couva District are derived consist of marine sedimentary deposits of Miocene age. They have been named the *Manzanilla Formation* by G. A. Waring. The formation consists of sands, clays and sandstones. The clays and sandstones are generally calcareous.

On the northern boundary of the area, and particularly in the north-western corner, patches of clay and sandy soil occur which are derived from geological strata known as the *Caroni Formation*. Waring states that no distinct change is noticeable in the character of the deposits that occur near the division between the Manzanilla and the Caroni beds, which runs in a north-easterly direction across the north-west corner of the area covered by the soil map. Here large areas of sandy soils occur, some of which are derived from the Manzanilla Formation and some from the Caroni Formation. It is interesting to note that the soils undoubtedly derived from the Caroni Formation (loose sands and red clays) are generally very unproductive.

Overlying the red Caroni clay on the tops of low ridges, a thin layer of reddish-brown sand is found. This may be derived from the *Matura Formation* mentioned by Liddle as occurring in patches in thin layers over the Caroni Formation.

We are greatly indebted to Dr. W. Rohr and Dr. Ambuhl, geologists attached to the Trinidad Leaseholds Limited, for the information which they have given us concerning the type formations of the district.

(3) Methods of Survey.

The field work consisted of two parts:—

(*a*) *The preliminary survey.*—During our first visits, no samples were taken for analysis. The particular area under discussion was traversed with an auger, and spot samples were taken to a depth of 2-3 feet for the purpose of describing the superficial characters of the soil types. The spots were plotted on a large-scale map. During the preliminary survey, sites were selected for the location of profile sample pits.

(*b*) *Profile sampling.*—The area which had been previously traversed was visited a second time, and profile soil samples were taken from 6 foot pits dug on the selected sites.

In addition to the usual routine analyses carried out on all profile samples, the top 6-inch layer of soil from certain sites was selected for the determination of manganese and available phosphate and potash. It is intended eventually to determine available phosphate and potash on the top 6-inch layers of soil from all the profile sites, but the complete results will not be available in time to be included in this report.

Samples of the parent rock material from which the main soil types are derived were selected for a full analysis of their chief constituents.

The analytical results have been tabulated in detail for each of the profiles so far studied. The tables of data are not reproduced in this report, but are available for consultation in the College Chemistry Department.

(4) Description of Soil Types.

(I) Chocolate Soil.

(A) Distribution.—This soil type occupies approximately 2,000 acres in the Gran Couva District. On the soil map, chocolate-soil areas are coloured brown. The centre of the area is Hospidales Hill, on the northern slopes of which Salvador Estate, belonging to Mr. J. d'Abadie, is situated.

(B) Superficial Characters.—The chocolate-soil is a fairly heavy textured clay-loam. The surface soil possesses a characteristic chocolate-brown colour. The colour changes to a paler brown at lower depths. The parent rock from which

this soil type is formed is a porous calcareous sandstone, which weathers to a brownish material. The sandstone contains many fossils, together with dark-green specks of glauconite. The original colour of the unweathered material is also dark green. Throughout the chocolate-soil area, many slabs of brown calcareous sandstone occur on the surface in the cacao fields. In profile, the sandstone is usually encountered at a depth of 5 to 6 feet.

Being of a fairly heavy texture, the chocolate-soil does not dry out to an injurious extent during periods of drought. On the other hand, the porous sandstone which underlies it provides ideal drainage in times of excessive rainfall. Cacao trees growing on this soil type produce heavy crops.

(C) Sampling and Analyses—Chocolate Soil.

The following seven sites may be taken as typical chocolate-soil areas.

Site 3. Hill piece	..Esperanza Estate.
Site 6. Merce field	..Salvador Estate.
Site 7. Euloyo field	..Salvador Estate.
Site 21. Hospidales field	..San Pablo Estate.
Site 29. Jose Sanchez	..Tortuga Estate.
Site 33. Mi Carno field	..El Carmen Estate.
Site 38. Sta. Rosa field	..San Juan Estate.

A number of other profile pits, sunk in areas which have been marked chocolate-soil, are not quite characteristic of this particular type, since they are located close to the Brasso Clay-Chocolate soil boundary, and the soil is mixed.

(D) Discussion of Results—Chocolate Soil.

(*a*) *Texture.*—The soil is a medium-textured clay-loam, and shows a tendency to be lighter textured in the lower layers of the profiles, except for the Esperanza profile (No. 3), which shows a similar texture throughout the profile.

(*b*) *Reaction.*—The soil is slightly on the acid side of neutrality except where calcareous layers are encountered, when the reaction is markedly alkaline. In the San Juan profile (No. 38), there is a markedly acidic layer from 1 foot to 5-foot depth, and in the Esperanza profile (No. 3) there is an acidic layer from 2 feet to 4 feet. All sites show a tendency towards an increase in acidity in the middle of the profiles.

(*c*) *Organic matter content* is high, and penetration is deep, appreciable quantities (0.7 per cent.) being found down to 2 feet depth. In the Tortuga profile (No. 29), organic matter is not present in appreciable quantities below 12 inches, but this site is on a steep slope where the soil would be subjected to more than usual wash from heavy rains. On the other hand, in the San Pablo profile (No. 21) organic matter is present in appreciable quantities down to 4 feet depth.

(*d*) *Nitrogen* is high in all profiles, and its distribution follows that of organic matter.

(*e*) *C/N Ratio.*—The average C/N ratio for the top 6 inches of soil is 6.7, which is a fairly low value compared with other good yielding Trinidad cacao soils.

(*f*) *Calcium Carbonate.*—The chocolate-soil is derived from parent rock containing over 40 per cent. $CaCO_3$, but in the majority of profiles, all but traces of carbonate have been leached out of the top layers. In the Tortuga, San Juan and San Pablo profiles, no appreciable quantities of carbonate were found even down to the 6 foot level.

(*g*) *Available Potash* varies greatly in the different profiles, very high values being obtained at sites 33 and 21.

(*h*) *Available Phosphate* also varies considerably, but always shows a fairly high value. The lowest value is exhibited at site 6, Salvador Estate.

(II) Brasso Clay Soil.

(A) Distribution.—This soil type covers a very large area in the Brasso, Caparo and Gran Couva Districts. Patches of Brasso Clay Soil are found on every estate within the district except Salvador. Large areas of this soil type extend to the south and to the east of the area covered by the soil map.

(B) Superficial Characters.—The Brasso Clay Soil is a medium-textured silty-clay. The surface soil varies in colour, but is generally dark-grey with a characteristic greenish tinge. The subsoil is greenish-yellow, and at lower depths, greyish-blue, with a characteristic flakey, graphitic texture. The parent rock is a blue-grey impervious claystone, which is sometimes calcareous and sometimes gypseous.

Wherever the Brasso Clay soil-type is found, landslips are liable to occur in the wet season. During dry weather, the soil cracks badly, and during the rainy season the water percolates through these cracks to the impervious blue silt below, where it forms a slippery surface. When this occurs on sloping land, the top-soil often slides down the valley. Such landslips are of frequent occurrence in the Brasso and Gran Couva Districts, and large areas of good-bearing cacao are frequently destroyed. After a landslip has occurred, the parent blue clay is turned up and cacao cannot be replanted until the land has been allowed to weather for some years.

The porous brown sandstone which gives rise to the chocolate-soil overlies the Brasso Clay, and where these two formations meet, extensive landslides occur, for example at La Maraquita and San Juan Estates. These slides are undoubtedly due to water percolating through the porous sandstone to the impervious clay below.

Some good cacao cultivations occur on the Brasso Clay soil-type, but field observations have shown two oustanding drawbacks, namely:

(1) The frequent occurrence of landslides.

(2) During severe droughts, the cacao suffers very badly, and dies out in patches.

On a few small areas where the cacao has failed owing to drought or landslides, teak has been planted, and has grown very well.

(C) Sampling and Analyses—Brasso Clay Soil.

Special attention has been paid during sampling to the barren patches. Pits were sunk in good areas and in bad areas. The following sites may be taken as examples of Brasso Clay Soil profiles in this district.

Good areas:

Site 1. Mango field	..Esperanza Estate.
Site 9. San Pedro field	..San Pedro Estate.
Site 18. Marcellin field	..San Pablo Estate.
Site 28. Jehenn Eustache field	..La Victoria Estate.
Site 30. Willie field	..Tortuga Estate.
Site 41. No. 9 field	..La Gloria Estate.

Bad areas:

Site 5. La Marguerite field	..Esperanza Estate.
Site 11. Herman field	..San Pedro Estate.
Site 20. Penco field	..San Pablo Estate.
Site 24. Baccan field	..Tortuga Estate.
Site 26. St. Ann's field	..La Victoria Estate.
Site 27. Peter field	..La Victoria Estate.

D) Discussion of Results—Brasso Clay Soil.

(*a*) *Texture.*—The soil is a medium-textured silty clay, which dries out and cracks badly in dry weather. In the field, the surface layers of the soil tend to become hard and compact.

(*b*) *Reaction* varies in the different profiles. For the majority of good sites, the reaction is slightly on the acid side of neutrality, except where calcareous layers are encountered.

On the bad patches, the reaction is slightly acid on sites 20 and 26, and highly acid on sites 5, 11 and 24.

(*c*) *Organic matter content* is fairly high in the top layers, but appreciable quantities are not generally found below the 12 inches depth. Site 26 is exceptional, 0.8 per cent. of organic matter being found at 3 feet depth.

(*d*) *Nitrogen* is high in all sites, and follows the distribution of organic matter.

(*e*) *C/N Ratio* is low for all sites, the bad sites showing slightly lower ratios for the top 6 inches than the good.

(*f*) *Calcium Carbonate.*—The parent blue silt from which the Brasso Clay soil-type is derived, contains abundant fossil remains, and analyses of the bottom layers of the profiles showed varying small amounts of calcium carbonate up to 9 per cent. Traces only of carbonate were found throughout the profiles sunk on the bad patches, except sites 20 and 27.

(*g*) *Available Potash* varies from 63 p.p.m. at site 41, to 110 p.p.m. at sites 11 and 28. Compared with critical values given by various authorities, these values are neither high nor low. The bad patches show no tendency to give lower values than the good patches.

(*h*) *Available Phosphate* varies from 21 p.p.m. on site 11 (San Pedro Estate) to 111 p.p.m. on site 18 (San Pablo Estate). Compared with critical values, 50 p.p.m. may be regarded a medium value. The average value samples taken from good patches is 76 p.p.m., and from bad patches, 32 p.p.m.

(III) Brasso Sands Soil.

(A) Distribution.—Large areas of sandy soils, and sandy-loam soils occur in the Gran Couva District. These sandy soil types differ somewhat in nature and productivity.

(B) Superficial Characters.—In the Central Range hills proper, the sandy formation is found chiefly along the course of the Couva River, and gives rise everywhere to good-bearing cacao. Thus San Juan and San José Estates contain large areas of sandy-loam soil lying near the banks of the Couva River, both on the vega flats and on the undulating land in the immediate vicinity. The soil type at La Vega Estate is predominantly sandy, with a mixture of Brasso Clay in patches. Very productive sandy soils also occur in Philippine Estate, bordering the Savonetta River. Another large area of sandy soil stretches from north Philippine Estate through El Reposo Estate, and through part of Santa Maria, Santa Isabella and El Dorado Estates. The cacao in this area is said to have been good-bearing some years ago, but is now in poor condition, and yields are low. This area also suffers very badly from thrips.

Further north of this area, in the north-west corner of the soil map, large areas of coarse, loose sand occur which are very unproductive. The hilltops are generally uncultivated, supporting such vegetation as *Cecropia* and *Cocorite* palm, but in the ravines, and along the banks of the streams, some fair cacao cultivation exists.

(C) Sampling and Analysis—Brasso sands soil.

The following sites may be taken as examples of the Brasso Sands soil-types.

Site 13. Bel Espoir field	..Philippine Estate	Support good bearing cacao.
Site 22. Garcia field	..San Pablo Estate	
Site 36. Middle piece	..San Juan Estate	
Site 37. Franco Savannah	..San Juan Estate	

Site 4. No. 2 field	..Esperanza Estate	Support healthy cacao which does not have a high yield.
Site 15. Olefi field	..Philippine Estate	
Site 44. No. 4 field	..La Gloria Estate	
Site 40. Parson field	..El Reposo Estate	Cacao poor and yield low.

(D) Discussion of Results—Brasso sands soil.

(*a*) *Texture.*—The sandy soil types vary in texture from fine loose sands (such as occur at Esperanza Estate (site 4) and at Philippine Estate (site 13) to sandy loams, such as occur at San Juan Estate (sites 36 and 37) and La Gloria Estate (site 44)). In the El Reposo profile (site 40), a hard compact cemented layer was encountered between 1 foot to 3 feet depth.

(*b*) *Reaction.*—On all sites, the soil is markedly to highly acidic throughout the profiles. The San Pablo profile showed the least acid reaction, and the Esperanza and Philippine profiles, the most highly acid reaction.

(*c*) *Organic matter content* varies considerably, being highest in the San Pablo, San Juan and La Gloria profiles. Organic matter content of the subsoil is very low, no appreciable quantities being found below 12 inches depth.

(*d*) *Nitrogen* is high for the top layers, and follows the distribution of organic matter.

(*e*) *C/N Ratio* is low, except for site 36 (7.4 for the top 6 inches) which is situated on flat ground near the Couva River. The poorer-yielding sites show a lower ratio (average 5.2) than the good yielding sites (average 6.2).

(*f*) *Available Potash* has so far only been determined at two sites (40 and 37), which give values of 63 p.p.m. and 96 p.p.m. respectively.

(*g*) *Available Phosphate* varies greatly in the different profiles. The highest value is given by the San Juan site, No. 36 (92 p.p.m.), and the lowest value by the El Reposo site, No. 40 (18 p.p.m.). The good-bearing sites give appreciably higher values than the poor-bearing sites.

(IV) Caroni Red Clay Soil.

(A) Distribution.—Extensive patches of this soil type occur within the area and are mapped in the north-west corner of the soil map. Small patches also are found at Corsica Estate.

(B) Superficial Characters.—The surface soil has a characteristic reddish-brown colour. Wherever cacao cultivation has been attempted on this soil type, it has generally been quickly abandoned. In the Caracas District, sugar-cane is grown with some success on ridges of this red clay, which are generally covered with a thin layer of reddish-brown sand. On San Philippé Estate, a considerable area of red clay soil-type has been planted in Teak, which appears to be quite healthy, although growth has been rather slow.

(C) Sampling and Analyses—Caroni Red Clay Soil.

Only one profile has so far been sampled on this soil type, *i.e.*, Site No. 20, Acho's contract, Philippine Estate.

(D) Discussion of Results—Caroni Red Clay Soil.

(*a*) *Texture.*—The soil is a stiff compact silty-clay on the surface, and a compact fine silt, below 30 inches depth. Red and grey mottling is noticeable below 12 inches depth.

(*b*) *Reaction* is highly acid throughout the profile.

(*c*) *Organic matter* is present in fair quantity in the top layers, but no appreciable quantity is found below 12 inches depth.

(*d*) *Nitrogen* is fairly high in amount, and follows the distribution of organic matter.

(*e*) *C/N Ratio* of the top 6 inches is very low (5.5).

(*f*) *Available Potash* shows a medium value of 80 p.p.m.

(*g*) *Available Phosphate* is very low (22 p.p.m.).

(V) River Alluvium Soil.

The alluvial soils of the Gran Couva District, occupying the banks of the Couva River and the Savonetta River, are of a sandy type, and support good-bearing cacao.

No sample pits have so far been dug on alluvium, but culturally the soils are similar to the sandy-loam soils (Brasso Sands) at San Juan Estate (Sites 36 and 37).

(5) General Conclusions.

(*a*) *Texture.*—The soils of the Gran Couva District vary in texture from silty-clays to fine sands, and good bearing cacao occurs both on heavy and light-textured soils.

(*b*) *Reaction.*—The heavier-textured soils are generally slightly acid in reaction, except where calcareous layers are encountered. The Caroni Red Clay and the bad Brasso Clay patches are highly acid in reaction.

The good-yielding Brasso Sands soils show a slightly acid reaction in the top layers, and are highly acid at lower depths. The poorer-yielding sandy soils are highly acid throughout the profile.

(*c*) *Organic Matter* is present in fair quantity in the top layers of all profiles, but penetration in appreciable quantities below 12 inches is unusual, except in the Chocolate-Soil profiles, where penetration is noticeably deeper than in the other soil types.

(*d*) *Nitrogen* is generally high in the top layers of all the profiles.

(*e*) *C/N Ratio* throughout is low, both on good and bad sites. The average value for the good sites is 6.6 and for the bad sites, 5.7 for the top 6 inches.

These results afford additional confirmation of the findings of Hardy and Griffith (*i.e.*, that good-yielding cacao soils have a wider *C/N* ratio for the top 6-inch layer than poor-yielding soils). Low C/N ratios indicate the need for mulching with wide ratio materials; any easily decomposable vegetable matter, excepting perhaps leguminous material, would be suitable.

(*f*) *Available Phosphate.*—Available phosphate in the top 6-inch layer of soil from 26 sites has been determined. From the tabulated results, the following indications are apparent:—

(*a*) Available phosphate varies very greatly in the different profiles.

(*b*) The highest values are obtained at the Chocolate-Soil sites.

(*c*) The average value for good-bearing sites is 150 p.p.m., and for poor-bearing sites, 29 p.p.m.

From a comparison of good and bad sites, it seems probable that the available phosphate content of cacao soils is a very important factor in their productivity.

(Available phosphate is being determined on the top 6 inches of soil from all sites, but the results will not be available for inclusion in this report.)

(*g*) *Available Potash.*—Available potash has been determined on the top 6 inches of soil from 13 sites. The indications, as follows, are inconclusive:—

(*a*) The highest values are obtained at the Chocolate-Soil sites.

(*b*) The average value for the good sites is 164 p.p.m., and for the bad sites 82 p.p.m.

(*c*) Many good-yielding sites exhibit values below 82 p.p.m.

(*d*) Good Brasso Clay soils have an average value of 77 p.p.m. of available potash, while bad Brasso Clay soils have a higher value (87 p.p.m.).

(6) Summary.

A soil survey of the Gran Couva District of the Central Range area which surrounds Gran Couva Village, Trinidad, has been attempted, and the main soil types have been differentiated and mapped.

Profile soil samples have been taken at 44 different sites within the district for examination in the laboratory. From the results of these analyses, the characters of the different soil types have been described and discussed.

These results have also given interesting indications of certain factors which appear to be related to the productivity of cacao soils, namely:—

(*a*) The results have confirmed the important relationship between the C/N ratio for the top 6-inch layer, and the productivity of cacao soils.

(*b*) The results have indicated that the available phosphate content of cacao soils may have an important bearing on their productivity.

Our work in this area is by no means finished. The preliminary survey above described is intended to form a basis for further more detailed work which will be carried out in co-operation with the College Department of Economics. This scheme is already in progress, and individual fields at La Vega and Salvador Estates are being sampled in great detail in an endeavour to identify these soil factors that are most closely correlated with high yield of cacao.

III. Outline of intended further Research.

Section I.—Environmental Study.

(*a*) The routine measurements of environmental conditions at the two cacao plots ("good" and "bad") will be continued during 1932.

(*b*) Soil samples will be taken every fortnight for the determination of Ammonia, Nitrate and Total Nitrogen contents.

(*Note.*—The work completed during the past year has afforded additional confirmation of the important relationship which the C/N ratio of the top 6-inch layer of soil, bears to the productivity of cacao soils. The determination of the various nitrogen fractions has been initiated with the object of obtaining exact information on the nitrogen status of these two plots which differ so widely in yielding capacity.)

(*c*) Leaf samples are being taken once a fortnight for the determination of Moisture, Total Nitrogen, Phosphate and Potash contents, with the object of investigating the effects that differences in soil conditions produce in the chemical composition of the leaf, and possibly of other parts of the cacao tree such as the seed.

Section II.—Cacao Soil Survey.

(*a*) The soil survey of the Gran Couva District will be extended into areas lying to the east and north of the area already surveyed.

(*b*) The relationship between various soil factors (*e.g.* C/N Ratio; Available Phosphate; Available Potash), and the productivity of cacao soils will be examined in greater detail, particularly with respect to the top 6-inch layer of soil.

(*c*) It is intended as far as possible to obtain some information on the nature of the chief soil types under natural forest conditions. For example, the Basin Hill Forest Reserve bordering the Central Range cacao lands on the east occurs largely on Brasso Clay soil. Profile samples taken within this reserve should therefore provide interesting comparison with similar soil that has been under cacao for many years.

APPENDIX.

Cacao Research Scheme—Schedule of Expenditure.

	Actual for year to 31st August, 1931.	Actual for year to 31st August, 1932.	Estimated for year to 31st August, 1933.
Salaries	£1,263	£1,492	£1,567
Pensions	126	149	157
Ocean Travelling	66	57	57
Apparatus and Chemicals	242	274	275
Laboratory Attendants	127	174	190
Field Supervision and Labour ..	86	67	200
Local Travelling	256	370	329
Contingencies	185	—	—
Administration Charges	250	250	250
Publications	—	10	100
	£2,601	£2,843	£3,125
CAPITAL EXPENDITURE : Apparatus, &c.	£150	£71	